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MECHANISM OF THE POCKET WATCH.*

BY H. E. DUNCAN.

The lecturer was introduced by Dr. Coleman Sellers, Professor of Mechanics, and spoke as follows:

LADIES AND GENTLEMEN:

Of the several branches of fine mechanics, that of horology has ever been one of the most fascinating. Like most of the useful arts, its early history is wrapped in more or less of mystery. Early writers mention the fact of the existence, in their times, of mechanical devices for the purpose of measuring time, but usually leave the reader in doubt as to the mechanical design or plan upon which they were constructed. Writers as early as the eleventh century make such mention. The earliest productions, in all branches of horology, were very crude, and their mechanical construction such as would

* A lecture delivered before the Franklin Institute, December 7, 1894.

be expected where the workman entered an unexplored field in which he was so sadly handicapped by lack of suitable tools and of the knowledge necessary to make them.

Watchmaking, so-called, or the construction of a portable time-piece of such size as to be readily carried upon the person, must have severely taxed the mechanical abilities and the patience of the artisan; but, as I have mentioned, there is a certain fascination to one mechanically inclined, who enters this branch of fine mechanics. I imagine these pioneers in watchmaking caught this fever, and that they could not stop, if they would, until death relieved them from its fascination.

This I call the Infant Age of watchmaking. I am of the opinion that there is not at present in existence a watch of this age.

It is not the purpose of this paper to deal with the watch historically, beyond presenting what is necessary to convey to you an idea of the particular basis upon which the *American system* of watch manufacture was established. With regard to these earlier watches, I will only remark that they had but one hand, and that they served only to mark the hours in a very indifferent manner. The next period of advance worthy of note is one that I call the Age of Handicraft. This period is marked as one in which the workman showed great progress in the mechanical execution of his work. He learned to execute parts in a very delicate manner, to give them graceful shapes, and to polish, in a masterly manner, those parts made of steel—his gain in handicraft enabling him to make movements in many odd forms and sizes. Artists in gold, silver and enamel, made and decorated cases for his movements. Most beautiful specimens of these cases are to be found in many collections of the present time. These watches were most artistic throughout, in *appearance*, but they still remained of but little value as time-keepers.

From this stage the improvement in time-keeping qualities becomes very marked. Large bounties were offered by Act of Parliament for portable time-pieces sufficiently accurate to ascertain the longitude at sea. These awards

were not for elaborate cases, or for fancy polish of mechanical parts, but for *actual performance* as time-keepers.

This period was one in which the watchmakers made a study of the laws of physics, and made practical application of them in the construction of ships' chronometers, and with such good results that, by the year 1769, there had been paid to Harrison the sum of £10,500.

It was but a step to reduce the size of this time-piece to a convenient pocket size, and watchmaking entered its scientific age. At first glance it might appear that with a knowledge of the scientific laws to be observed in the construction of watches, and with workmen sufficiently skilled in handicraft to execute them, watchmaking had reached its final stage of development. If the product of *hand labor* had been equal, in mechanical accuracy, to that of machines, this condition would have been reached, but such was not the case. Results obtained by instruments of precision depend almost entirely on the absolutely uniform operation of automatic mechanism; while, notwithstanding the highest degree of manual skill, the quality of the final product of his handicraft will still be affected by the personal equation of the workman.

This brings us, then, to the next great event in watchmaking; one falling within the present century, and due wholly to American mechanics:

THE MECHANICAL AGE OF WATCHMAKING.

The American system was not based upon new scientific discoveries, or upon any radical change in existing models, but it revolutionized the method of manufacture.

In place of some tool or fixture guided by the hand of a workman, a machine was constructed, especially adapted to the piece to be made, cams and levers taking the place of the hand and eye of the workman, the result being greater accuracy in the finished piece, and, consequently, a closer approach to perfection in the watch as a whole.

For many years American watch factories had machines for making but few models of watches, but to-day the American Waltham Company has a plant in which it can

produce a watch of any design or size of model that the world's market may demand.

In mechanical accuracy, time-keeping qualities and price, it cannot be equaled.

The pocket watch is one of the most accurate of all instruments of precision. Briefly defined, it is, mechanically, a spring motor, of most delicate construction of parts, controlled by an automatic regulating device that is a marvel of precision. It is designed to measure accurately and record the hours, minutes and seconds of the mean solar day. A watch, keeping time to a minute a week, varies from true precision by only one hundredth of one per cent. The act of winding, so-called, is that of storing energy in a spring. By this act of winding, the hand, in an interval of about fifteen seconds, stores up energy enough to keep the motor in motion and to supply the maximum of power required, for a period of twenty-four hours, and with a reserve, in the *modern* watch, of about sixteen hours; or, in other words, the modern Waltham watch will run for a period of forty hours from the energy that is stored in it by the hand in fifteen seconds of winding—9,600 times the length of time employed in winding.

The storage of power is effected by means of a ribbon of steel, of a width and thickness proportioned to the size of the watch, and contained in the first wheel, called in technical parlance the barrel, which is in the form of a cup. The size of this cup is governed by the size of the watch, being of nearly one-half the diameter of the frames of the watch.

This spring, in its natural form, is of the shape shown on the screen, and is from eighteen to twenty-five inches long. It is coiled up in the barrel, with its outer end secured by means of a pierced hole fitting over a suitable hook or stud projecting inward from the barrel. Its inner end is secured, by a similar hook, to the hub of a wheel called the first or main wheel. By the act of winding, this spring is wrapped around this hub, and the wheel is caused to revolve. The tension imparted to the spring in winding it about this arbor, is the force tending to drive this first wheel of the watch. The moment of this force is equal, on an average

in a watch of "gentleman's size," to that of a pull of five ounces troy on a wheel of one inch radius. The action of the spring, in performing its duties in the watch, will readily be understood by observing the one on the screen.

To show, in the most simple manner, the hours, minutes and seconds of the mean solar day by three separate hands or pointers would require three wheels or gears, with such ratios of diameters and teeth, that *one* wheel would make one revolution in twelve hours; the next, twelve revolutions in this time; and the third, 720 revolutions. But this simple plan would give two hands going in one direction and the third hand in the opposite direction, while custom demands that the hands of a watch shall all move in the same direction. To correct this reverse motion of the third hand, two more wheels are required, and their use, in other respects also, is beneficial rather than otherwise.

The wheels and pinions, or, technically speaking, the train of a watch, is a system of gearing driven by the stored energy in the main-spring. These wheels and pinions are so proportioned to one another in respect of their diameters and numbers of teeth, that when driven at the proper rate of speed they will serve to register hours, minutes and seconds by means of hands fixed to them.

The necessary frames to hold these wheels and pinions are called plates—the upper and the lower plate. The train of wheels would perform the work required of it just as efficiently if the wheels were arranged with their axes in a straight line, and for the present I will use this arrangement in my explanations.

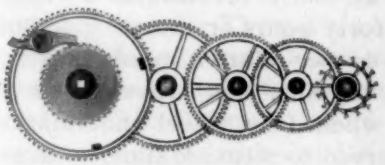

FIG. 1.

This arrangement is seen in *Fig. 1*. At the left we have the main-spring in its barrel. This drives a steel pinion, that has fixed to it a wheel No. 2, technically known as the centre wheel and pinion. This centre wheel and pinion is intended to revolve once in an hour. It is the wheel to which the minute hand is fixed. It serves to mark the

fractions of an hour expressed in minutes. In turn, this centre wheel drives pinion and wheel No. 3. This is called the third wheel and pinion. This third wheel, in turn, drives pinion and wheel No. 4. This fourth wheel revolves once a minute, or sixty times faster than the centre wheel. It is to this wheel that the second hand is fixed. Returning to the third wheel, I will explain that its use is to cause the fourth wheel to revolve in the same direction as the centre wheel, so that the hands will move in the same direction. It is also useful in allowing the distance between the centre and fourth wheels, to be varied. Otherwise the distance apart of the minute and second hands on the dial, would be governed by the size of the centre wheel and fourth wheel pinion.

You will note that there is one more wheel and pinion in this train of wheels, namely, the last one, which is called the escape wheel and pinion, but, as it belongs to the time-governing part of the watch, called collectively the escapement, I will speak of it under that head.

I now place on the screen the train wheels of a Waltham watch, with the main-spring fully wound. When the brake is removed, all begin to revolve rapidly, as you see, and they will continue to do so until all the stored-up energy of the main-spring is exhausted. The watch has now run down, but the wheels have made as many revolutions as they would have done in running forty hours or more. Each of the wheels has traveled at its proper relative speed; that is, the fourth wheel, showing seconds, has traveled sixty times as fast as the centre wheel (the wheel that marks the minutes), but it has not served to measure time, because of the lack of any contrivance to govern or regulate the speed.

This controlling or regulating device is called the escapement.

The detached lever escapement was invented about the year 1765 by Thomas Mudge, a famous English watchmaker. It is the escapement used at present in nearly all good, sound pocket watches. It can be said for it that, when made with ordinary care, it is so reliable in its action

that it is generally selected in preference to all other escapements for pocket watches.

The action of this escapement is to bring to a standstill every wheel in the train, and, after a brief period of rest, to allow the train to start again, only to be as quickly stopped again, and so on. These alternate steps of progress and halt succeed each other so rapidly, however, that probably very few persons realize that the motion of the time train is always intermittent, and not uniformly continuous.

With the exception of the escape wheel, the teeth of all the wheels of a watch are formed on the epicycloidal curve, so as to mesh into, and give motion to, the several pinions with the least friction or loss of power. The teeth of the escape wheel are for a different purpose, and they act in an entirely different manner.

FIG. 2.

You will notice by *Fig. 2* that the teeth are not in radial lines, but are so inclined as to form a series of hooks. Also notice that the ends of the teeth are of a wedge form. The angle formed by the straight sides of the teeth and the inclined top is called the locking corner, and the angle of the inclined top is called the impulse or lifting face. Engaging with the wheel is a piece called the "pallets and fork," and of the form shown on the screen (*Fig. 3*). The pallets are shown by the two black projections or horns, and are made of some kind of precious stone, such as sapphire, ruby or garnet. The remaining part is of steel, and serves to hold these pallet stones in place.

FIG. 3.

The long arm with divided end is, from its shape, called the fork. The fork and pallets are mounted on an arbor that allows them to swing or vibrate, and placed so close to the escape wheel that one or the other of these pallet stones is sure to lock into a tooth of the wheel. By means of the accompanying sketches I will endeavor to explain the action of the escape wheel and pallets.

Fig. 4 shows the escape wheel with one of its teeth resting against the left-hand, or so-called receiving, pallet stone. It is now in the position called "locked" or "at rest," and it

will remain in this condition until, from some cause, this pallet is moved backward sufficiently to permit the locking corner of the tooth to pass this flat face of the pallet stone. The wedge-shaped end of the tooth will then still further lift, or move the pallet, as shown in *Fig. 5*, and it will continue to lift the pallet until the wheel is free to pass under it, when a tooth, in advance of the one in question, will be caught by its locking-corner on the face of the other, or so-called releasing, pallet-stone, as shown in *Fig. 6*. Here it will remain until the pallet is withdrawn sufficiently to allow the tooth to pass under, when the former action will take place at this point, and the wheel will again be

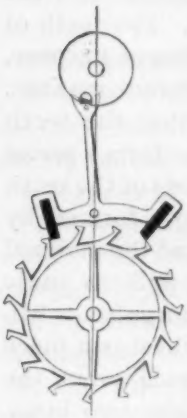

FIG. 4.

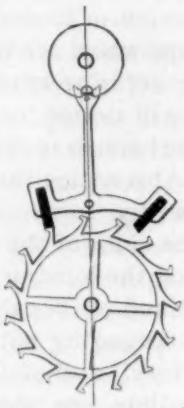

FIG. 5.

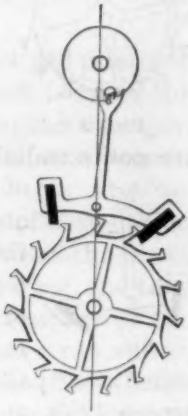

FIG. 6.

brought to rest, in the position noted in *Fig. 4*. Here we have the rotation of the escape-wheel converted into vibrating motion at the pallets. The long arm serves to increase this angular movement, and it is the medium through which this vibrating motion is communicated to the balance through what is called a roller (*Fig. 7*). This is a small disk with a pin near the outer edge, made, as the pallet-stones are, from some precious mineral. This disk is shown, with its pin, at the upper part of *Figs. 4, 5* and *6*. It is on the same arbor as the balance and hair-spring, and it moves with them as they vibrate.

FIG. 7.

Imagine the roller and pin, shown in *Fig. 4*, to be, by some cause, rotated slightly to the right and toward the slot in the end of the fork. The pin would then enter and strike against one side of the slot in the end of the fork, and move, together with the pallets, in the same direction until the escape-wheel tooth was unlocked, when the lifting end of the tooth, passing under the pallet on that side, would continue to drive the fork to the right. This, in turn, would assist the pin in the same direction, as shown in *Fig. 5*, until it passed beyond this influence, as shown in *Fig. 6*. Here the "fork and pallets" await its return that it may first and then give impulse, in the opposite direction, through unlock this roller and pin, to the balance.

This act of unlocking, that it may receive impulse, is, in the case of clocks, performed by the pendulum, acting under

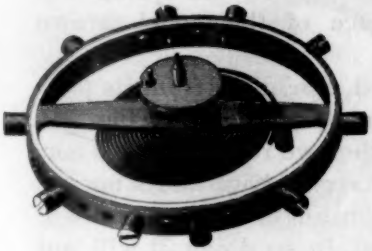

FIG. 8.

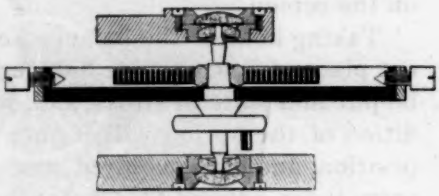

FIG. 9.

the laws of gravity; while in portable time-pieces, the balance takes the place of the pendulum, and the hair-spring that of the force of gravity. The balance, hair-spring and roller are all mounted on a staff, or arbor, *Fig. 8*, which runs on very delicate pivots, or bearings, not much larger than an ordinary hair. I show you now, on the screen, a very striking camparative illustration of the size of these pivots, namely, a photograph of the largest balance pivot used at the Waltham factory, and the eye of a No. 10 sewing needle, made with the aid of a microscope. These pivots run in jeweled holes, with additional jewels, called end stones, at their ends.

You will see by *Fig. 9*, that the pivot will always rest on jewels, in whatever position the watch may rest. These

fine jewels shown are the ones usually broken in case of accident to the watch. The balance wheel will be explained later. It is placed midway of the staff; and above it is placed the hair-spring, a very delicate spring made from a flat piece of steel wire, about nine inches long, one-hundreth of an inch wide, and two and one-half thousandths of an inch thick, weighing about 9,000 to the pound. This spring is shown in *Fig. 10.* It is coiled in the form of a flat spiral, having its inner end made fast to a little split collar, known as the collet, which collar is forced on to the balance staff or arbor.

FIG. 10.

The outer end of the hair-spring is pinned firmly to a small stud, called the balance cock, which is held rigidly to some part of the frame of the watch.

The relation existing between balance and spring will be understood with the assistance of the model thrown on the screen.

Taking hold of the balance and moving it from its present place of rest, say one-half turn or more, the spring will be put in a state of stress, and, when we release it, this condition of the spring will at once carry it back to its normal position, and the acquired momentum of the balance will carry it far beyond that point, but, in so doing, it will put the spring in a state of stress, in a direction opposite to that in which we strained it by turning the balance by hand.

When the momentum of the balance ceases to exceed the opposing force of the hair-spring, the revolution of the balance in that direction will cease, and immediately the hair-spring, will begin to act, carrying the balance back again; but, as in the former case, the momentum of the balance will carry it beyond the point of rest, and so the motion will be repeated, in alternate directions, each vibration being shorter than the preceding one, until the balance finally comes to a stop. It is this action of the balance and spring that is made use of to unlock the escape wheel, as the balance is returning from its excursion. This is done by the action of the roller and pin that move with the

balance on its staff. As the balance returns from either direction, *Fig. 4* or *6*, toward the point of rest, *Fig. 5*, the roller pin engages with the slot in the fork, and the momentum of the balance and the tension of the spring, are sufficient to unlock, without apparent effort, the escape wheel. The instant this takes place, the wheel, by reason of the form of its tooth, and urged by the power of the mainspring, instantly avails itself of the position of the roller pin in the fork, and gives the balance a push, as it were, in the direction of its motion. This push, or impulse, is sufficient to make up for all loss, due to friction and other

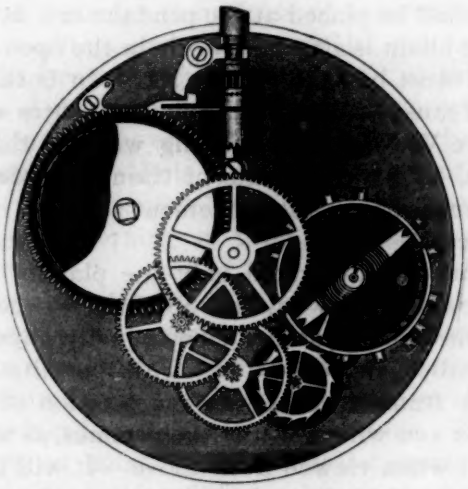

FIG. 11.

causes, which, but for this impulse, would, in a short time, bring the balance to a state of rest.

At each excursion of the balance, it has work to do in unlocking the escape wheel, and in turn it receives enough new energy to keep up its full motion. These pulsations are very rapid, five each second, 18,000 each hour—almost too rapid for the eye to follow. I place on the screen a very slow moving watch that you may better study its action. * * *

For simplicity, I have illustrated the watch with its train

and escapement arranged in a straight line, but this, of course, is not the actual arrangement in the watch. Here in the watch, *Fig. 11*, the wheels of the train are arranged between circular frames, with the centre wheel, as its name would lead us to imagine, placed in the centre of the frame. By arranging the hour and the minute hands concentrically, one series of graduations upon the dial is made to serve for both, and the use of the third wheel allows a little leeway in planting the position of the second hands, when the watch is designed, relative to its distance from the other hands, in the centre of the watch. Custom demands that in a watch movement, cased in a hunting case, the figure III on the dial shall be placed at the pendant and bow, or ring, to which the chain is attached, while in the open-face watch the pendant must be at the figure XII. In both cases, the second hand must be on a line from the centre of the dial to the figure VI. In stem-winding watches this requires two models, or arrangements of train, in order that the winding connections in the movement shall be in line with that of the case.

I have thus far illustrated only the plan of the watch, that is, a view such as would be obtained by looking down upon it. I now show another view, equally important, that is properly called the elevation. This permits us to look between the frames, and to see the position of the parts, which I trust you will recall by their names, as well as their arrangement when viewed from above. It will also permit me to explain the arrangement of two wheels and pinions, which serve to cause the hour hand to make but one revolution around the dial, while the minute hand is making twelve.

The centre wheel has one of its arbors long enough to reach through the watch frames on the dial side, and has, fitting on it, friction-tight, a steel pinion, called the cannon pinion. This pinion drives a wheel in a recess in the plate, a wheel usually three times its size; and a pinion, fixed to this wheel, in turn drives a wheel four times its diameter, with a centre in the form of a tube nearly as long as the cannon pinion and fitting freely around it. This arrange-

ment of sizes causes this last or hour wheel to move twelve times slower than the cannon pinion. To the cannon is fixed a minute hand; to the hour wheel, the hour hand. The spring friction of the cannon pinion, in the arbor of the centre wheel, permits this set of wheels to slip, thus avoiding injury to the train or escapement in setting the watch.

* * *

I will return for a moment to the balance and hair-spring, which I called the automatic governor of this spring motor.

Without touching upon the constantly occurring and often violent and sudden changes in the position of the watch, I will consider the effects of temperature, which is constantly varying, and often quickly and between wide limits. The structure of the hair-spring of the watch, presenting, as it does, so much surface, in proportion to its total mass, is such as to render it particularly sensitive to thermic influences. It is a well-known law of nature that all metals expand under the influence of heat, and that springs lose something of their elasticity with a rise in temperature.

Applying these laws, it is found that heat causes the balance to increase in diameter, and the hair-spring to lose some of its elasticity. From these two causes the watch loses time by a rise in temperature, while the opposite effect will be produced by a fall in temperature. The effect of temperature on balance and spring is corrected by what is called the compensating balance, invented about the year 1782. This is so constructed that the same heat which weakens the elastic force of the hair spring, serves at the same time to reduce the diameter of the balance, so as to exactly adapt it to the force which the weakened spring is capable of exerting. This automatic compensation is obtained by constructing the balance rim of two metals, having widely differing ratios of expansion. In the ordinary watch, the two metals employed are brass and steel. The inner portion of the rim being of steel, with an encircling band of brass, and the two metals being firmly united by fusion, the action of this form of a balance will readily

be understood by a few words of explanation in connection with the diagrams on the screen.

Fig. 12 represents two strips of metal, brass and steel, of equal length at normal temperature. Under the influence of heat, or of cold, these strips will expand, or contract, in about the ratio indicated by the dotted lines. Now, if the brass were firmly united to the steel, as in *Fig. 13*, and if their respective thicknesses were in the ratio of three of brass to two of steel—then the brass would not be free to expand, or contract, being held by its union with the less expansive steel, and the result would be that, when heated, the bar would curve, as in *Fig. 14*, while, when cooled, it would curve in the opposite direction, as shown in *Fig. 15*.

FIG. 12.

FIG. 13.

FIG. 14.

FIG. 15.

The next two figures will show how this law of expansion is utilized in the construction of compensating balances.

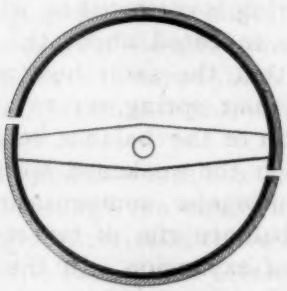

FIG. 16.

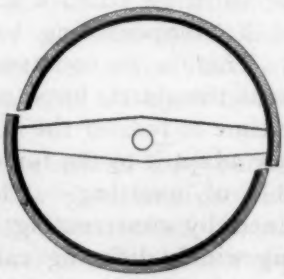

FIG. 17.

The first of these, *Fig. 16*, shows the balance with its rim of brass and steel, at normal temperature; the next, *Fig. 17*, shows the form it assumes when heated. You will

observe that the rim of the balance has been severed at two opposite points and near the arms, leaving the cut ends free to move out or in, by changes of temperature. In the next drawing, *Fig. 18*, you will notice that the balance has received an addition in the shape of screws with large heads.

These have a double use. First: to give the balance the exact weight desired, so that, in conjunction with a proper hair spring, it shall make the exact number of vibrations required per hour, which in most modern watches is 18,000. In making this number of vibrations, the rim of an ordinary balance will travel 3,479 feet, or nearly eighteen miles per day. Now, if for any reason the balance were to omit only ten of these vibrations in an hour, the watch would

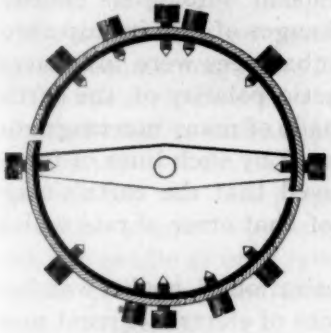

FIG. 18.

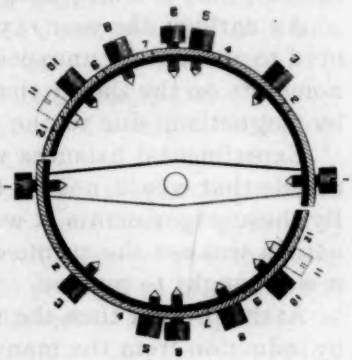

FIG. 19.

have lost two seconds of time, or forty-eight seconds per day, over three-fourths of a minute. The addition of one of these little screws to each side of the balance, will reduce the number of its vibrations, amounting, in some conditions, to as much as ninety-eight seconds per hour, or thirty-nine minutes per day.

I will now make plain to you the second use of these little screws. In this view we have the screws numbered, *Fig. 19*, and you will observe that between the screws are holes, which are adapted to receive screws, and these holes are also numbered. A careful and accurate trial might show that at a normal temperature (about 70° Fah.), this balance would have the proper size to give its required number of

vibrations, but by subjecting the watch to an increase of twenty-five degrees in temperature, it might be found to lose as much as seven seconds per hour, or thirty-five vibrations. This fact will indicate that when in heat the balance is too large; or, more properly stated, the effective weight is not properly located, being too far from the axis. In this case we would move screw No. 3 to position marked No. 11, thus giving an added weight to that part of the rim where the effect of the heat would cause it to curl in toward the axis and thus allow more rapid vibrations.

Manipulations of this sort are always required in adjusting watches to temperature.

I now show on the screen the motion of a watch balance in heat, that you may note this action. * * * * * *

As early as the year 1837, European horologists endeavored to account for unexpected changes of rate in ship chronometers on the theory that their balances were influenced by magnetism due to the magnetic polarity of the earth.

Experimental balances were made of many non-magnetic metals that would not be influenced by such lines of force. By these experiments it was proved that the earth's magnetism was not the prime cause of that error of rate which it was sought to remove.

At the present time the magnetization of pocket watches by induction from the many sources of electric current now so commonly in use, makes the question of furnishing a non-magnetizable watch one of the prominent problems of modern watch manufacture.

A pocket watch will show but little if any change of rate that can be traced directly to the influence of magnetism due to the earth's polarity, but by placing the watch within the influence of an intense artificial magnetic field its rate will be seriously affected. Magnetic fields, of an intensity sufficient to stop the watch, are to be found on every hand, and if the wearer knowingly or otherwise, ventures into the lines of force, the watch will instantly adapt itself to the well-known laws of magnetic induction.

There are two well known laws of magnetism that apply to watches.

The first is that any so-called magnetic metal, placed in the field of a magnet, will itself become a magnet, and will retain this magnetism in a more or less marked degree when removed from the field. Steel is an excellent example of such metals.

The second law is that similar magnetic poles repel, and dissimilar poles attract, each other.

By applying these laws we arrive at a full understanding of the effect of magnetism on a pocket watch of the usual construction, and an explanation of its loss of value as a timekeeper.

A watch, in the field of a magnet strong enough to stop it, will usually, when removed, at once commence running again, but its time-keeping qualities will have been ruined. It is true that it can be de-magnetized, but this, while a relief, is no permanent cure, and the watch will again become magnetized upon similar exposure.

On the screen we have the shadow of a magnetized piece of steel called a magnetic needle.

You will note that when the horse-shoe magnet approaches the needle, the latter assumes a condition of sympathy with the magnet's polarity, but when we reverse the magnet, the needle at once reverses its position so as to conform to the previous conditions of attraction and repulsion of magnetic poles.

The horse-shoe magnet is the stronger of the two, and the needle, being free to revolve, responds to its polarity. If the needle were not free to move, the horse-shoe magnet would reverse the magnetism of the needle. * * *

It is safe to say that in the majority of cases, when watches have been found to be magnetized, it has happened at some time unknown to the wearer, who has wandered into the field of a powerful motor or dynamo. When a watch stops in a magnetic field, it is because the magnetism is strong enough to hold the balance.

A magnetized watch has a very irregular rate. A marked gain or loss of time will usually be followed by the opposite condition, these alterations varying in quantity at different hours of the day. The more marked the polarity

of the watch, the greater will this variation become. In the pocket watch, we have in particular two pieces of steel that absorb and retain magnetism, when brought into the field of a magnet. I allude to the main spring and the balance (see *Fig. 9*). The former, owing to its mass and hardness, is the greater quantity. The spring, as you will recall, is a long ribbon of steel, in a cup or barrel, which, when fully wound, is in a small coil, in the centre of the barrel, wrapped around the arbor, and, when run-down, is in much larger coils, which have expanded until they have filled the barrel. We have here, at the extremes of fully-wound and run-down, two laminated rings of magnetized steel that show polarity, but the direction of this polarity changes as the spring passes from the condition of fully-wound to that of run-down.

Here we have a magnet that changes its polarity through the whole period during which the spring is passing through its changes in driving the watch. The other particularly important part of the watch in the study of the problem, is the balance. You will recall that its arms and part of its rim are of steel. They consequently become polarized, but this polarity, unlike that of the main-spring, remains a *constant* factor. In the case of the coiled main-spring, its polarity appears to take nothing from the stored-up energy of the spring, but in the balance we have a different condition. We have done all that could be done to remove friction, or to make it constant, and to eliminate the factor of change of rate by changes of temperature, only to meet, in our polarized balance, a new factor, due to one of the laws of magnetism that I have stated. Its poles will be attracted, or repelled, by other polarized bodies near it. When the balance is in place in the watch and free from any influence of the train, its spring should return to the same place of rest or quiescent point. This place of rest is one in which its spring is free from tension; but the moment the balance becomes polarized, it immediately tries to place itself in sympathy with this new condition, and disregards the previous relations with its spring in regard to the place of rest. There is at once established in

the spring a state of stress to oppose this. The spring is no longer natural in its action. Were all these disturbing elements constant factors, the result would be a constant error (*Fig. 20*).

But this is not the case. The polarized main-spring is constantly revolving and presenting its ever-changing magnetic poles to those of the balance. At times these are in sympathy with its own polarity; again they are exactly opposite. In one case the balance will make its excursions too quickly, in the other not quickly enough.

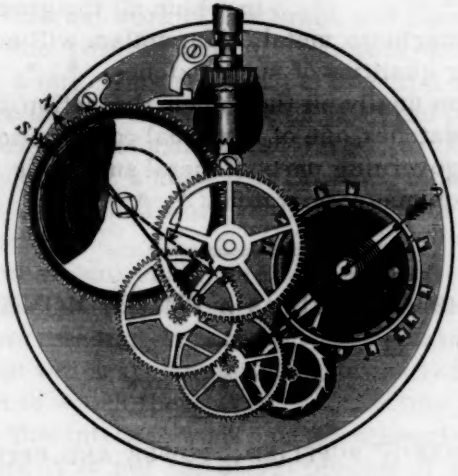

FIG. 20.

In one case the watch gains, in the other it loses. I have on the screen a magnetized balance and spring in the position they occupy when in the watch. A test by a small compass needle shows them to be polarized. Vibrate the balance and it returns to its former place, which is in sympathy with the polarity of the steel spring in the barrel. We revolve the barrel a little and the polarity changes and the position of the balance responds to the change of polarity presented by the barrel. * * *

The hair-spring comes under these laws, but, being less in mass than the balance, its polarity is not so important a factor.

But the slide on the screen shows a balance of non-magnetic metals with the usual steel hair-spring, and you will see it is a little influenced by the polarity of the main spring.

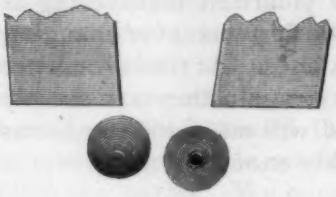

FIG. 21.

I have on the screen two watch hair-springs (*Fig. 21*); one of non-magnetic metal, the other of the usual metal, steel. The magnet serves to distinguish them. * * *

A non-magnetic watch is one in which all the governing parts are of non-magnetic metal. Magnetism will not affect the time-keeping qualities of such watches. * * *

I show you finally on the screen the action of the magnet on two watches, one of the usual construction, the other with all its governing parts of metal such as is used in the Waltham non-magnetic watch. * * *

THE ANIMAL AS A PRIME MOVER.

BY R. H. THURSTON.

PART II. ENERGY SUPPLIED; POWER AND EFFICIENCY; INTERNAL WORK OF THE VITAL MACHINE.

The energy expended by the vital machine consists of:

(1) The external work performed as the task of the workingman.

(2) The external work performed incidentally outside of that useful work, as in the movements of the limbs, walking, handling the food and various voluntary and other motions, which constitute a considerable fraction of the more or less necessary expenditure of energy in ways not included in the daily specified task.

(3) The internal work of digestion, assimilation, nutrition, and rejection of excreta.

(4) The internal work of respiration.

(5) The internal work of circulation of the blood and the other fluids of the system.

(6) The internal work of growth, maintenance, reconstruction and repair.

(7) The internal work of the automatic system regulating the functions and movements of the various organs, both external and internal.

(8) The internal work of conscious direction of the movements of body and limbs, and, in some cases, of internal organs, and, to some extent, of the work of respiration and of circulation.

(9) The internal work of the brain, and possibly of other organs, in the performance of conscious thought and of brain-work, a large part of which is essential to the proper performance of the useful work of the vital prime motor, and in the case of the man whose duties are those, distinctively, of the thinker, a large part of which must be rated as useful and prescribed work, determining the efficiency of the machine.

(10) Peculiar and characteristic forms of energy which are the special produce of some organism or class of organisms, and not essential elements of its operation as a vital machine, but which are employed occasionally as the special provocation to which they respond comes into action.

Such is the internal work last mentioned—that of the brain—where it is not the useful product of the machine; such is the energy expended in the production of the poison of the serpent, the secretion of offensively odorous fluids in many animals and, perhaps, the honey-producing glands of the bee may be thus classed. The most remarkable, and, in this connection most important, illustrations of this class, are found in the generation and use of the electric fluid by the torpedo and gymnotus and the production of light by the glow-worm and fire-fly.

Hybernating animals exhibit a peculiar modification of the action of the vital functions; their whole purpose, during hybernation, being to insure of the continuance of the physical operations of circulation and respiration by the employment of the previously stored energy of the accumu-

lated fat of the body. Very little tissue is wasted or repaired and the whole system is simply preserved in action through a period of temporary suspense of the life of the creature. That this may be done by the employment of pure hydrocarbons indicates that only energy and not material is required, for no nitrogenous aliment is absorbed or assimilated.

The measure of these various quantities of energy, useful and wasted, necessary or incidental to the purpose of the existence of a machine or its application to useful work, is, in the case of the external useful work of a laboring man or animal, easily and accurately made; but all the other items are very difficult, and usually, at present, at least, impossible, of more than approximate measurement, even if any clue can be obtained at all to their methods of action or their absolute and relative quantities. We have not yet discovered the nature of the primary methods of transformation of the energies imported, as latent, into the system, or even what energies are active in the production of the work of the brain and nervous systems and in the automatic operation of the machine. We know enough, however, to prove that the animal machine is a motor of very high efficiency as compared with the prime movers devised by man, (his thermodynamic engines, at least,) and to indicate, if not to prove, that the machine is a thermo-electric, chemico-dynamic, electro-dynamic or chemico-electric apparatus, or else a prime mover in which some unknown form of energy, acting by as yet undiscovered methods, is transformed more economically than in any case familiar to the man of science or the engineer of our time.

The power of animal machines varies greatly with the race and work. Investigations of the quantity of work per pound of the animal machine have been made by the students of aviation, which throw some light upon the problem in hand.* Thus Dr. Smyth measured the lifting power of a pigeon, as registered by a dynamometer, and computed its expenditure at 160 foot-pounds per pound of bird, or about 200 pounds

*"Progress in Flying Machines." O. Chanute, p. 39.

weight of bird per horse-power. Alexander computes 270 foot-pounds per pound, 120 pounds weight per horse-power. Penaud finds the following, which are thought to be more exact figures:

	Pounds per horse-power.
Peacock	66
Pigeon	57
Sparrow	48
Seapie	26

Were the weight of the pectoral muscles, which actually perform all this work, made the basis of these calculations, these figures would range from thirteen to about five pounds only per horse-power, thus giving the limiting weight of motor machine. The actual work of rising in the last cases is greater by the amount of slip in the wings, and the bird computed to give sixty pounds per horse-power is more nearly twenty pounds, and the last given figure becomes more nearly five to two pounds than thirteen to five. In full flight, the demand for power is much reduced, and becomes probably 500 foot-pounds per pound, or at the rate of 0·015 horse-power per pound, sixty-six pounds of bird per horse-power. This flying machine is proportioned to give the higher power at starting, the lower in steady working. Their emergency performance is thus probably three or four times the average for the day's work. This is also a fact illustrated in common experience with men, who, developing one-eighth of a horse-power for an average day's work, can exert a half horse-power for two or three minutes, a full horse-power for a few seconds. The aggregate power of the machine varies from an indefinitely small quantity with the smaller creatures, to 140 horse-power, as estimated for the whale swimming ten knots an hour.

The heart is, perhaps, the most powerful and enduring of all the muscular structures of the system. Helmholtz has computed that this organ can, on the average, raise its weight at the rate of 6,670 meters per hour. He found that the locomotive, climbing heavy gradients, in the cases investigated by him, at that time, could rise 800 meters in the hour, unloaded. He, therefore, concluded that the heart,

considered as a machine, was eight times as effective as the locomotive. Presuming that his locomotive had an efficiency of ten per cent., this would make the heart, were it self-contained and a prime motor, exhibit an efficiency of energy-conversion of about eighty per cent. This supposition is however by no means correct.

Fick estimates the efficiency of energy-transformation in the useful work of the muscle at one-third to one-quarter, the remainder of the total energy supplied being consumed in internal work and wasted directly or indirectly as heat.*

Chauveau points out the fact that the efficiency of the muscle varies enormously with time and method of contraction and extension and magnitude of load. In the case of the muscles of the automatic- the vital-system, as those of the heart and lungs and digestive organs, it is probable that the conditions are those of constant maximum efficiency, and the figure attained would seem, from other considerations, to be likely to be found comparatively large, and, for the machine as an energy-transformer, immensely greater than is ever attained in non-vital motors of the thermodynamic class. The energy-transformation is presumably never thermodynamic, but is, directly or indirectly, dynamo-thermic and the heat of the muscular system is a product, not a source, of useful work, and an excretion, not a food.†

It has been seen that the food required by the average workingman contains about 12,000 B.T.U. of energy when resting or doing little work, and about 16,000 when at hard work. It would thus appear that the work of the laborer, for which he is paid, represents about twenty-five per cent. of all the energy expended by the vital machine in external and internal work, heat-producing and wastes. This means that it performs one-fifth of a horse-power of commercially valuable labor, and, assuming all work concentrated into the working day, three-fifths of one horse-power, mainly, in the work of the organism itself.

A day's work, even for the average workman of full working power, varies greatly with the nature of the work and

* Experimenteller Beitrag. 1869. Ueber die Wärmeentwicklung. 1878.
† Chauveau: Travail Musculaire, pp. 233.

the method and facilities of its performance, and the same is true of the horse and all other animals, but usually in less degree. The most powerful horses may be expected to develop, as an average, two-thirds of a horse-power for eight hours a day, or 12,000,000 foot-pounds per day, very nearly, under favorable circumstances. The work of a man is variously given by different writers, but it is usually stated to be not far, *at best*, from 2,000,000 foot-pounds per day in the tread-mill, ascending mountains and stairways when his own weight is the useful load, and carrying burdens on a level. Weisbach gives as maximum figures 1,935,360. Rankine gives 2,088,000, while Ruhlman states the work of a Prussian soldier, carrying a knapsack and other accoutrements weighing a total of 64 pounds, as about 3,000,000 foot-pounds. We may safely take 2,000,000 foot-pounds per day as a figure to be compared with the 10,000,000 foot-pounds of energy supplied, and as giving a fair maximum for the efficiency of the animal considered as a prime motor.* It is 0·125 horse-power for eight hours, 0·04 for the day.

The efficiency of the animal machine, as an apparatus for the performance simply, of external work, is, on the basis here taken,

$$E = 2{,}000{,}000 \;/\; 10{,}000{,}000 = 0{\cdot}20,$$

twenty per cent. This happens to be just the efficiency of the best recorded steam engine performance to date.

The efficiency of the vital machine, considered as a motor, is high. Haller, about 1840, had applied the then new principles of thermodynamics to the action of the vital elements of the system, and had suggested that the heat of the body was, at least in part, due to the friction of the circulation. Joule found, by experiment, that the passage of fluids through tubes gave rise to heat and gave the correct explanation, as early as 1843. In the now famous paper of Joule, dated 1846,† he concludes:

The duty of a Daniell battery, per grain of zinc, is 80

* The Animal as a Prime Motor. R. H. Thurston Sec. 17, p. 50; Sec. 18, p. 53.

† *Philosophical Magazine*, 1846. Memoir of Joule, by Osborne Reynold, 1892, p. 100.

pounds raised one foot high—about one-half the theoretical duty—*i. e.*, its efficiency is about 0·50.

The duty of a Cornish engine, per grain of coal, is 143 pounds raised one foot high, an efficiency of 0·10.

The duty of a horse, per grain of food, is 143 pounds raised one foot high, "which is one quarter the energy due its combustion," an efficiency of 0·25.

Joule thus, at the middle of the century, had found the animal, taken as a prime mover, to be two and a half times as efficient as the best engines of his day, one and a quarter times as efficient as the best engines of our day, the close of the nineteenth century.

This figure is corroborated by many independent experiments and computations. Joule, as above, put the work of horse and man at about one-fourth, sometimes as low as one-sixth, the dynamic equivalent of the food-supply. Hirn found substantially the same figure as is above deduced, by measuring the work and the exhalations of carbon-dioxide and of moisture by his enclosed tread-mill operators. Helmholtz deduced 20 per cent., also, from the same experiments. Joufret takes the work of the man at 280,000 kilogram-meters and obtains 21 per cent., by the day, rising to 37 per cent., short intervals and actual expenditures of energy and proportional supply being taken.

We may thus, without much doubt, conclude:

The efficiency of the animal machine, assuming that only external, so-called useful work is reckoned as the product, and the full dynamic equivalent of the energy latent in the food-supply being taken as unity, is about 20 per cent.* Hirn's experiments with his enclosed tread-mill gave efficiencies from 17 to 25 per cent., the lowest being given by "a lymphatic youth of eighteen," the highest by a strong laborer of the age of forty-seven. The average is precisely that computed by the method pursued above.†

Our computation, however, should be checked by the introduction of the quantity of rejected, unassimilated food,

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* **The Animal as a Prime Motor.**

† *Ibidem*, p. 43.

if we are to learn the real maximum possible efficiency of the animal machine motor.

The factor of digestibility is probably with the animal machine, human or other, when in good health and normal, between 75 and 90 per cent., averaging not far from 80 or 85 with the customary healthful foods. With domestic animals, Professor Woods finds this factor to range all the way from about 50 to approximately 90 per cent.* This is confirmed by many other investigators, and the assumption of 85 per cent. as a fair maximum is probably perfectly justifiable, with all the familiar forms of the vital machine in good order.

In the case of Weston, the pedestrian—studied by Dr. Flint—the proportion of food utilized being taken as measured by the ratio of nitrogen absorbed in food to that excreted in chemically different combinations, the efficiency of nutrition, the "factor of digestibility," in one sense, was, when quietly training without excessive exertion and with very moderate exercise, and as an average for five days, 86·6 per cent.† It is probable that a good digestion and assimilation should be expected to attain an efficiency of 90 per cent., and that 10 per cent. of the food, or less, might be expected to be wholly wasted. Very nearly this efficiency was attained by the same individual during five days of recuperation after a five days' walk of 317·5 miles.

The food of the human prime motor has been seen to yield from about 2,500 calories, 10,000 B.T.U., 7,800,000 foot-pounds, nearly, when doing little or no work, up to 4,000 calories, 16,000 B.T.U., 12,500,000 foot-pounds, nearly, when doing a maximum day's work. This would seem to indicate that the internal work of brain, nerves, muscles and other organs of work and thought and heat production, must be about three times the total external work of a working day, and this, in turn, would again make the efficiency of the vital machine one-quarter, 25 per cent., corresponding once more to the maximum given by Hirn's direct experiments.

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* Reports of Conn. Agricultural Experiment Station.

† "Muscular Power, p. 84.

Reviewing what has been thus far collated, it will probably be admitted that the following may be taken as a fair estimate of the efficiency and energy distribution of the average representative human prime motor, assuming 10,000,000 foot-pounds supplied and 85 per cent. of the food to be digested:

THE ANIMAL MACHINE.

RECEIPTS AND EXPENDITURES—EFFICIENCIES.

Received Food-content.	Energy Utilized.	Per Cent. of Energy Available.	
Total receipts (foot-pounds) 10,000,000			
Loss, unassimilated 1,500,000			
Available and utilized	8,500,000	85·0	100
One day's labor, maximum	2,000,000	23·5	20
Heat rejected*	3,700,000	43·5	37
Thought-energy	500,000	5·9	5
Internal work other than friction	2,300,000	27·1	23
Wastes by non-assimilation, as above			15
Total	8,500,000	100·0	100

* Dalton.

Where the machine is a *thought-machine*, and not primarily a prime motor, the efficiency may be quite different, as will be seen later.

The wasted energy of the vital machine, when considered merely as a work-producer in the ordinary sense of that term, consists of the various internal energies expended in the operation of the machine, the misapplied mechanical energy of the twenty-four hours, and the heat radiated and conducted from the body and exhaled from the lungs. Could all these wastes be suppressed, the efficiency of the machine would be unity as a prime motor. Precisely what are these energies and their respective amounts is, as yet, unknown; their aggregate has been seen to be 80 per cent. To what extent either or all may be suppressed, as our knowledge of the machine enables us to employ it more and more intelligently, no one can yet say, except that it is known that the losses of heat from the exterior of the body may be kept down to a comparatively small amount, and, if necessary, made minute, by properly clothing it in non-conducting

materials, precisely as nature clothes the birds and the other wild creatures. If the suppression of this loss results in corresponding increase in energy-conversion, in useful directions, the efficiency of the machine is to that extent exalted. It is certain that some loss of heat externally is necessary to preserve the activities of organs of the body, by giving a needed difference of temperature between the surface and the interior, and to carry away energy in its final, thermal form; and mankind has, from the beginning, sought to reduce this waste by covering the body with skins, woven tissues, and other forms of material fitted to check the outflow.

The source of animal warmth and heat energy has been, for generations, the subject of study and experimental research by the best physicists and biologists. According to Jamin, Messrs. Halles and Cigna and Black and Priestley, showed that the products of respiration were chemically identical with those of combustion. Lavoisier confirmed this conclusion, and proved that the oxygen inhaled was not all accounted for by the exhalation of carbon-dioxide, but a balance must be sought in the production of water, by union with hydrogen. He attributed the vital functions to the oxidation occurring in the lungs, and circulation to digestion and to the regulating action of transpiration. Regnault and Reiset, measuring the volumes of carbonic acid produced, found that the larger the proportion of vegetable food, the greater the amount of this oxidation; while the combination of oxygen directly with the carbon of the nutriment sometimes gave an item in the balance of the account, its rejection occurring with the fluids of the system, as in uric acid, this proportion being the greater as the food was, in larger part, flesh. They found a small amount of nitrogen passing off, presumably rejected from the disintegrating tissues. Boussingault reached the same conclusions by determining the quantities of solid and liquid taken into the body and rejected from it. Lagrange, Spallanzani, Edwards and Magnus ascertained that the oxidation occurs in the circulation and the capillaries. Despretz and Dulong found the heat produced by the vital apparatus

to be about nine-tenths the quantity which would result from complete oxidation, in equal amount, in the air.*

The source of vital and muscular energy is easily identified, and it is well known that the function of digestion is to render available the potential energy of the foods by reducing them to solution in fluids capable of easily and rapidly and completely entering the constitution of the blood, to be distributed to points in the system at which their stores of potential energy may be made available in kinetic form. Precisely how this latter operation of transformation occurs is still unknown; but Claude Bernard, about the middle of the century, called attention to the action of the hepatic system in the production of glycogenic matter, and later investigation has shown that glycosic matter is distributed throughout the animal system from the liver and through the circulatory system into the capillaries, where it largely disappears and carbon-dioxide comes into view. It is now well understood that the oxidations and the energy-transformations essential to animal life and activities occur through reactions between the oxygen in solution in the blood of the arteries and the combustible elements accompanying it, which chemical operations take place in the depths of the tissue cells, and, perhaps, in the capillary vessels. It is also now admitted that the quantity of action is probably proportional to the loss of sugar and of oxygen, and to carbonic acid replacing the lost glycose as a product of its oxidation.† Since these chemical combinations are invariably low-temperature combustions, and since they are vastly greater in quantity in the active than in the passive muscle, and since the heat ultimately derived is the *excretum* of the system and the final result of energy-transformation, it may fairly be concluded that an intermediate transformation, or series of transformations, as yet unidentified, either qualitatively or quantitatively, constitutes the physiological method of production of work. Glycosic substance is not found concentrated in any considera-

* An interesting corroboration of recent measures of the "coëfficient of digestion."

† See Chauveau and Kaufmann. Comptes rendus, t.ciii, 1886.

ble quantity in the tissues, except in the liver, the organ in which it originates, and the only conclusion would seem to be, that glycogenesis is the one extremity of a chain of transformations, of which heat constitutes the other. In this sense the hepatic gland is the source of muscular power, as well as of animal heat. It is this fact which makes the flow of blood to the working part, and the volume of its channels, measures of the energy there applied.* The weight of blood flowing through a muscle at work was found by Chauveau and Kaufmann to be about eighty-five per cent. of the weight of the muscle itself, each minute of working time, for full load. Its amount varies with the work performed, external and internal. The circulation, with the muscle in repose, was found, by the same investigators, to be about one-fifth as great as when in full work. The succession of changes is thus, probably, as follows:

(1) Potential energy in foods is rendered available as a source of kinetic energy by change of the foods into the various constituents of the blood by chemical action and the expenditure of some probably small net amount of chemical energy.

(2) This available potential energy is transferred to the capillaries by the blood, and its elements are selected by each organ for its own special development of mechanical work or of other and active energies.

(3) Chemical combinations take place, resulting in the production of active forms of energy, applicable to the special work of the organ, as mechanical work in the muscle, chemical action of characteristic kinds in the glands, nerve-power in the nervous system, and the accessories of thought in the brain.

(4) The internal energies, though useful, objective forms, each being utilized in the performance of its special work, are subject to a final transformation, and are at last converted into heat, and passed outward to be excreted by the skin and the lungs.

The latest researches indicate very positively that the

* Chauveau and Kaufmann. Comptes rendus, t.civ. 1887.

production of heat in the vital prime mover is partly due to nutrition and tissue repair, or rather its breaking down, and not all necessarily derived from the simple and direct oxidation of the combustible matter of food. It is even uncertain whether the potential energy of food considered as a fuel, and of its combustion in air, is to be taken as precisely measuring its energy available for the work of the vital machine. Chauveau considers the glycogenic product of the liver, distributed to the tissues, the source of all mechanical and thermal energy. The sound animal machine can work vigorously about eight hours a day; the remaining sixteen hours are devoted to repair, reconstruction and energy-storage. Eight hours each day, one-third of life, is given especially to the reparation of the brain and mental powers.

Dr. Edward Smith has shown, by experiment upon himself, that the inspiration of air and the production of carbon-dioxide may vary in the proportion of one to ten, accordingly as the individual lies sleeping or actively exerts himself in the tread-mill or in running at top speed, the exhalations of CO_2 ranging from 5·5 grains to forty-five grains per minute.* The quantity becomes, for the given case, six grains when standing, twenty when walking, and twenty-five or thirty when walking rapidly. The variation seems to be approximately, in Smith's tables, as the square root of the speed of the pedestrian. Since the total work of the machine must vary as the velocity of overcoming a fixed resistance, as the cube of velocity where the resistance increases with the speed-square, as is here presumably the fact, it would seem from these facts that the interior resistance must be a rapidly increasing proportion of the total work performed, internally and externally, a deduction which is confirmed by constant and familiar experience. The experiments of the same investigator, however, seem to prove the variation of the exhalations when at rest, directly with the difference between the external and the internal temperatures; which, if corroborated fully, would indicate the heat of oxidation in the body to be ordinarily employed

* "Foods." International Series. New York: D. Appleton & Co.

principally in the maintenance of its warmth at the standard point. This makes it advisable to ascertain more exactly what energy is measured by the chemical actions resulting in the production of other rejected compounds, solid and liquid, and to learn, if possible, whether chemical action in one case produces the demanded thermal energy, and in others the required chemical or other motive energy.

These various deductions indicate that one-tenth or thereabouts of the energy of oxidation in the tissues of the body and in its capillaries finally produces work of various kinds; that nine-tenths passes as heat; that the efficiency of energy-conversion is thus ten per cent. On the other hand, the fact that external work alone gives transformation of twenty per cent. shows that both internal and external work must find ultimate conversion into heat from some other and antecedent form of energy of food-conversion and chemical action.

Rejected heat-energy increases rapidly with increase in the amount of work performed by the machine, and this seems to confirm the idea that the expenditure of internal energy in the accelerated operations of circulation, respiration and nutrition, must find ultimate conversion into heat and rejection in that form. The disappearance of thermal energy observed by Hirn is proof of this action. Hirn also found that the total heat exhaled exceeded by one-third that computed, and thus proved that it must be derived, in part at least, from other processes than combustion. The quantity was five calories, when resting, about half as much when at hard work, per gram of oxygen inhaled. Mental effort and work have precisely the effect of manual labor in this increase of the heat-waste and conversion of energy. The source of energy as an effect of oxidation would seem to be the food taken into the system and the broken-down tissues of muscle, bone and nerve, while the office of the food-supply is to replace this tissue, and to furnish the energy of chemical action as well.

Dalton* and others take the heat-waste of the human

* "Human Physiology," Philadelphia, 1875, p. 302.

machine as about 200 B.T.U. per hour, 1·28 B.T.U. per pound, nearly, or a total for the day of 4,800 B.T.U., equivalent to 3,734,400 foot-pounds. Assuming the possibility of complete suppression of this *as waste*, or what is equivalent to the same thing, its application to internal work of equal value with the energy applied to useful external work, the efficiency of the animal machine becomes

$$5{,}734{,}400 - 10{,}000{,}000 = 0{\cdot}57 + ;$$

over fifty-seven per cent., and exceeds that of any known form of thermodynamic machine in actual use, nearly three to one.

Whether the suppression of this waste, with corresponding gain in useful conversion of energy, can be effected, remains uncertain, and is perhaps unlikely to be practicable, although animals and human races in the tropics often live for long periods in temperatures at which no conduction or radiation of heat is possible and must depend entirely upon evaporation of moisture from the exterior of the body for its distribution. Since it certainly, in part, at least, represents the re-transformed energy of internal work, it would seem probable that only by effecting a balance between internal and external work of that class could this waste be completely suppressed. This is probably impossible with the vital engine, but nothing is known that would indicate similar necessary limitations in any artificial machine in which the essential transformations of the vital machine may in some way, possibly, be illustrated.

As has elsewhere been suggested, it seems certain that all the internal operations of the body, all the various methods of energy-transformation, must result in final reduction of their resultant total to the form of heat-energy, and, in that form, they pass away from the system. This conclusion is confirmed by the experiments of Rubner, who finds that the radiated heat of the animal body precisely measures the calorific power of the food utilized by assimilation.*

The internal work of the vital machine, as now computed,

* *Zeitschrift für Biologie*, xxx, 1893, p. 73.

amounts to forty-three per cent. of the energy supplied, less the amount of rejected potential energy of unassimilated food. Neither quantity has as yet been precisely determined. Estimates have been made, however, and possibly sufficiently approximate for present purposes.

Letheby, for example, proposes the following for an average day of the average workingman at his usual vocations involving some manual labor:

Foot-pounds, external work, actual labor	1,011,670
Work of the circulation	500,040
Work of respiration	98,496
Total foot-pounds	1,610,206

Adding to this probably very rough estimate the 3,734,400 — 598,536 = 3,135,864 for heat not due to these causes, we have a total of 4,746,070 foot-pounds, or about one-half of all the energy supplied. Reckoning the work, as before, at 2,000,000 foot-pounds, the total becomes five-eighths the energy-supply.

This leaves, at least, three-eighths to be accounted for, and if we may take the proportion of blood taken to the brain as a measure of its demand for energy, and, as estimated by Flint, at about ten per cent., we still have about twenty-five per cent. as unaccounted for. But it is certain that a part, perhaps a large part, of the heat rejected from the system comes of internal fluid friction and energy-transformations, and it is also certain that some of the food escapes digestion and assimilation. In fact, the loss in the latter form of supplied energy has been computed, in some cases, as fully twenty-five per cent.

It would thus appear possible, if not extremely probable, that the full amount of the potential energy of the food actually assimilated may be accounted for in one or another form of the resultant energies visible or sensible as external, and as essential internal, work in the vital machine. Just what internal work the external heat-flow may represent, it is impossible to say positively; but, assuming that all the energy expended in the circulation of the fluids of the body, all the work of friction, so appears, and that all

energy of internal mechanical work of other sorts, and of all chemical processes occurring within the system, also, is thus rejected as heat; and assuming that the energy of brain and nerve action is transformed into mental and unmeasurable energies of which we have no dynamic equivalent yet established, the animal machine, as represented by the human body, may be taken as having an efficiency measured by the ratio of the sum of useful muscular labor and brain-work to the energy supplied.

This is now seen to be probably not far from thirty per cent., and the machine is, thus viewed, one and a half times as efficient as any existing steam engine.

If the use of the machine may be taken to be the production of muscle and brain-work, and of the heat required for the comfort of the system considered as an intelligent creature, the efficiency becomes the sum of these three quantities, divided by the total receipts of energy, or substantially two-thirds, the only waste, on this basis, being that of unassimilated food, and the energy of formation of chemical compounds, of heat, and of dynamic energy, unutilized, in a comparatively small proportion.

Brain-work is the task, and thought the product, of the professional man. The mass and weight of the brain give us some interesting data for consideration, if not throwing important light upon the problem in hand. The average weight of the brain of a man is about three pounds, perhaps fifty ounces; that of the average woman is ten per cent. less, about 45 ounces. High brain-weights are 53·4 ounces, the weight of that of Agassiz, up to 64·5, that of Cuvier; while low weights are indicative of reduced working power, if not of capacity for intellectual action. It is, however, true that the largest brains have been those of the idiotic and the insane, and that the greatest genius sometimes possesses a brain of but average size or even somewhat less; yet insanity and idiocy only prove, in most cases, disease of the ordinary brain of whatever size, and individual cases afford no evidence *pro* or *con*. The important fact is that size of brain increases with the intelligence of the race, and that, when the weight falls below about two pounds, two-

thirds the average for our own race, intelligence is usually lacking. Cerebration only occurs, efficiently, with larger proportions of gray matter.

The average weight of the male brain in African races is about that of females of the European races, and that of their females is ten per cent. lower. The weights in Australian races fall to that of the African female in the case of the male, and ten per cent below this for the female, or thirty-nine ounces. The weight never exceds fifty-five ounces except among the most civilized races. The bodily functions may be maintained and manual labor performed with very low weights, as healthy idiots have been known having brains weighing less than a pound, (8·5 to 10·6 ounces). The cerebrum constitutes eighty-seven per cent. of the cranial contents.

The compactness and firmness of the brain substance and the comparatively small quantity of blood with which it is saturated, in its ordinary healthy condition, indicate, probably, a slow building of tissue and construction of the gray matter constituting the brain material proper, and is, perhaps, also to be taken as evidence that the organ is not, like the muscles, in the opinion of many physiologists operative by the destruction of its own substance. The proportion of nutriment, suitable for each organ, presented by the blood, varies considerably, and it may be the fact that, for this reason, at least, the volume of blood sent to the brain is not a gauge of the energy supplied it in that form; but the probably slow construction of the tissue of that organ, and the comparatively small proportion of nerve and brain-making elements in the blood, are in accord with the hypothesis that some approximation to the ratio sought may be thus obtained.

The proportion of blood flowing to the brain would make it appear that about fifteen per cent. of the potential energy supplied the body is expended in brain-work. The fact that a loss of one-third the average weight results in loss of power of cerebration, possibly indicates that one-third the brain-power is devoted, in civilized races, to intellectual work. The fact that life and bodily health may persist with one-

third the average allowance of brain would seem to show that one-third the normal brain-action may be required for the conduct of the purely animal operations of the system. The corollary of these two deductions would seem to be that the normal thinker expends one-third his brain-power upon the vital machine, one-third upon the incidental and accidental cerebrations of life, and one-third upon real, purely intellectual work. But the size of brain and its quality are both known to be factors in the determination of the magnitude and nature of its product intellectually, and it is very possible, probable indeed, that the intellectual mind, with a brain well adapted to its use, not only has an instrument capable of doing more and better work than the average-but makes more use of that instrument than does its neigh, bor of equal brain weight. It is for this reason, in part, that the figures here assigned for brain-work have been fixed upon. As a matter of simple proportion, the human machine, acting as a prime mover simply, develops from 1,000,000 to 2,000,000 foot-pounds of work per day. The best worker is, usually, also most intelligent, and, following the above suggestion, it may, perhaps, be assumed, in default of direct measurement, that the "brainless" worker —using that term in its vulgar acceptation—may perform the lesser amount, 1,000,000 foot-pounds, and that the intelligent worker may, under similar external conditions, produce 2,000,000 foot-pounds, and that the latter may use his brain and consume energy supplied by the average brain, in moderate amount as well. If the professional brain-worker does less physical labor and more brain work, he may substitute the one for the other, to a considerable extent, and we have assumed 1,000,000 foot-pounds as the measure of a brain-worker's day's work, in addition to the labor of carrying on the bodily functions and that of regular, moderate exercise. As yet, however, such figures are little better than guesses.

The efficiency of the thought-machine, as the "brain-worker" of modern times has become, cannot be estimated with even so much of accuracy and certainty as that of the same organism employed as a vital prime motor and mechanical

engine. The considerations presented in the last section and in some of the earlier portions of this discussion would seem to indicate that the energy demanded by the brain for transformation, presumably, in the operation of the apparatus as the instrument of the mind and the tool of thought, may be fairly taken as between five per cent. for the case of the workingman giving all his energies to his task, with little time and no strength for mental labor, and for the non-intellectual creatures most nearly approaching man in their constitution and structure, and ten per cent. for the average intellectual product of civilization, up to perhaps fifteen per cent. in the case of the steadily working professional brain-worker. This is mainly to be deducted from the energy applied by the laborer with his muscles to his daily task, and the efficiency account would, in such case, stand as a first and a rough approximation, perhaps, as follows:

THE INTELLECTUAL MACHINE.

RECEIPTS AND EXPENDITURES—EFFICIENCIES.

Received Food-content.		Energy Utilized.	Per Cent. of Energy Available.	
Total receipts (foot-pounds)	8,500,000			
Waste, non-assimilation	1,500,000			
Available and applied		7,000,000	82	100
One day's work (thought)		1,000,000	12	14
Heat rejected		3,000,000	35	43
Internal work, aside from friction		2,000,000	23	29
External work (moderate exercise)		1,000,000	12	14

This estimate makes the efficiency of the mental machine fourteen per cent. if based upon the energy actually offered it in the circulatory system, or twelve per cent. if based upon the total food supply. If the exercise taken can be made also commercially useful, the efficiency, on this assumption, becomes twenty-eight or twenty-four per cent., and if the essential work of the machine is taken as that of providing its operator with heat and brain-power it becomes fifty-seven or forty-seven per cent.; the internal work as here denominated being the only waste except that of non-assimilation of food.

Whatever may be taken as the proper method of reckon-

ing efficiencies from the utilitarian standpoint, it is obvious that, in one form or another, the machine—this vital engine—converts eighty or ninety per cent. of the energy received by it into new energies by transformation; and, taking the real waste in the scientific sense as that of the heat rejected, the efficiency for comparison with heat engines—in which but one purpose exists, that of providing a single form of energy, transforming all received into the mechanical form, so far as practicable—it is fair to say that the former, with its efficiency as thus stated at fifty-seven to sixty-five per cent., excels the perfect heat engine of our time enormously, has twice the highest theoretical efficiency of the best steam engine yet produced, and three times its actual efficiency under the most favorable conditions yet reported. To attain this efficiency of the vital machine, any heat engine acting under the laws of thermodynamics, *as applied to motors with fluid working substances*, the only forms as yet devised, must, if we take the temperature of the human body as its minimum, have a range of about 375° F., and a maximum temperature of about 475° F. These should be the limiting temperatures of the machine, if it were a thermodynamic engine operating under any such conditions as are now known to limit the action of the heat engines.

The maximum possible range of temperature in a mass of organic substance, of which fifty per cent., or more, is water, and the circulating fluid mainly a solution of organic substance, cannot possibly be much greater than the range between the freezing and boiling points of pure water. But the efficiency of the best heat engine known, even acting as a perfect thermodynamic engine, would not exceed the ratio $180/672 = 0{\cdot}27$, twenty-seven per cent., and its actual efficiency would probably fall below twenty per cent. The animal, the vital engine, certainly has *no* sensible range of working temperature, and no elastic working substance like the gases and vapors; but its efficiency, even as a work-producer alone, exceeds the above figure, and, as an energy-producer, its efficiency exceeds that of ordinary heat-engines several times.

The correct method of estimating the efficiency of the

vital machine is unquestionably that which sums up all its expenditures of energy, thermal, mechanical, mental, and determines the ratio of that sum of all energies so far as directly contributing to the purposes for which the dweller within the apparatus lives, with the total energy supplied during a period including at least one perfect cycle. Taken in this manner and in this sense, the rejected heat would seem to constitute the only real waste, and the efficiency of the machine, as a peripatetic residence for the soul, would seem to be fairly reckoned at not less than forty-five per cent. nor more than sixty-five, accordingly as one or the other of the units above taken are accepted—two to three times the maximum efficiency of the best-known heat engines.

The rejected heat-energy is precisely like that of the final heat-waste of the electric lighting system—the final form of energy subjected to transformations of greater or less complexity during the process of application, in some definitely demanded phase, to a prescribed purpose. Rejected heat is certainly not, in the case of the vital machine, "let down" from a higher temperature in the process of thermodynamic conversion, an essential characteristic of that form of prime mover. The machine is evidently not a thermodynamic engine.

[*To be concluded.*]

PART I—ERRATA.

THE ANIMAL AS A PRIME MOVER.

P. 10, line thirty-three, for "of" read "above;" p. 15, line twelve, for "cabbage, carrots," read "carrots and turnips;" p. 18, note that engraver has transposed hatchings for protein and carbohydrates.

ENGINEERING PRACTICE AND EDUCATION.

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[*Concluded from p. 56.*]

Stereotomy is a species of advanced descriptive geometry, and can easily be acquired by any one who is familiar the latter subject. It bears more especially upon the work of the engineer who is to erect large buildings where stone plays an important part, or masonry bridges.

Of surveying and topographical drawing, of course, every engineer ought to have some knowledge, but the principles of surveying are easily learned by any one who has a scientific training and some skill in handling measuring instruments, and nicety of execution can only be acquired by long-continued practice, and the greater part of this practice will have to be acquired subsequently. Surveying has sometimes been assumed to be the principal business of the civil engineer, and frequently a man who was merely a surveyor has called himself a civil engineer; but the progress of the world is sweeping this away, and a man who is merely a surveyor is no longer considered to be an engineer any more than a machinist is an engineer. Now, while the man who is to build roads or railroads will probably have to use surveying to such an extent that it will be necessary to give him in the school more than is given in the other engineering courses, nevertheless his practice will have to be acquired subsequently, and the instruction in those things that he cannot acquire later, or can only acquire later with a great deal of difficulty, should, on no account, be sacrificed for surveying.

When we come to the higher geodetic work, we have geodesy, and not engineering and hence it will not be considered here. Then as to shopwork, very similar remarks

to those I have made in regard to surveying, will apply. It is something in which every engineer should have some practice, but which should not be given at the expense of more important engineering work. Indeed, it would be extremely desirable that this should be acquired at the manual training schools before beginning an engineering course, and whenever the manual training schools are established everywhere as a part of the public school system, so that young men who wish to take an engineering course at some engineering school can first attend the manual training school, then the engineering schools will not need to teach so much shopwork and what they do teach will be of a more advanced character.

Coming, now, to the studies of the second class, we shall find that we may divide them into two classes, the first being those requisite for such specialties as can be developed by a suitable addition of certain lines of work, but where these lines of work depend upon the previous training that has been given; and second, those where a considerable knowledge of, and hence a drill in, chemistry is necessary. Among the first I should place: (1) bridges; (2) hydraulic engineering; (3) railroad engineering, with special reference to permanent way; (4) railroad engineering, with special reference to motive power and rolling stock; (5) marine engineering; (6) mill engineering; (7) naval architecture; (8) electrical engineering; and others as they might arise.

In the second class, on the other hand, I should place mining, metallurgical and chemical engineering, and others as they might arise.

The essential difference between these two classes is that, in the latter, a considerable knowledge of chemistry is required, and, consequently, that the student must have considerable instruction in elementary chemistry and in qualitative and quantitative analysis, before he is in condition to discuss the subjects pertaining to his special line; and hence, that for these courses, a certain amount of chemistry becomes one of the essential fundamental studies that the student cannot do without, and must be provided for at the

start by assigning the necessary time for it in addition to that needed for the other fundamental studies. When suitable provision is made for this, there remains, of course, less time for other subjects than there is in the other cases.

Of course, the amount of chemistry required is a matter of degree. In some lines of mining engineering it is not great, whereas, in metallurgical works, or in chemical works, the amount is decidedly larger.

Nevertheless, the one who is laying out any of these courses must bear in mind that they are intended to fit men to do primarily the engineering work of such establishments, and that it is not necessary that they should have as much chemistry as would be required by the analytical chemist. Hence, he should begin by considering what is the minimum amount of chemistry which it will do to put in the course; put that in, and then leave the rest of the chemistry, which it might be desirable to add, to take its chances with the other professional subjects, according to their relative importance in the special line of work for which the course is laid out.

Let us assume, now, that we have fixed upon the fundamental subjects, and the time that must be given to each. We are prepared, then, to map out the course to be pursued in the second class, or special line of studies, including whatever of the first class we deem wisest to insert in the list.

Were I to attempt to map out the details of what should be given in the case of each special engineering course in these special lines, I should need a whole course of lectures to elaborate it. I shall only say a little, therefore, about some general rules to be observed in making the selection:

(1) To drill the student in all the details of his profession, or to impart to him experience, is not possible in a school. Experience can only be gained after the school days are past, and he goes to work.

(2) To attempt to perfect him in those things that he will have to do when he first goes to work, at the expense of his later success, is a very short-sighted policy.

(3) Hence, the object to be attained should be, first, to so

arrange this work that he shall have to deal with such cases as are liable to arise in the practice of his profession, as with the actual details of a bridge, of a steam engine, of a locomotive, of a mill, etc., and thus become familiar with what he is likely to meet later on; and secondly, that he shall be taught how to go to work on these problems in a scientific manner, applying the principles that he has previously learned, thus teaching him what is the relation of his scientific study to the practical problems he will meet later in life.

Next, in regard to the third class of subjects, or those intended for general information, it is desirable to insert as much as can be inserted, without sacrificing the accomplishment of the main objects of the course.

Such subjects are, mainly, linguistic and literary studies. The first, however, if confined to the modern languages, are also, to a certain extent, professional; for, without modern languages, some of our most valuable engineering literature is closed to the student.

Having thus marked out the character and the scope of the studies that should enter into an engineering course of one or of another kind, it remains for me to speak of two subjects, viz.: (1) The graduation thesis, and (2) the extent to which laboratory practice in the engineering laboratories should be introduced into the courses.

First, as to the graduation thesis. It has always been the custom for the engineering schools to require of the students, before they are graduated, a thesis. The special feature required of a thesis should be that it shall involve an element of original investigation, and its chief object is to teach the student how to make, and to give him practice in making, original investigation on his own account. He should be made to feel that the problem is his own to solve. He should be encouraged to propose his own plans for the solution, and to submit them to some one member of the corps of instruction, who should aid him when he needs aid, and exercise so close a supervision over his work, that he should be made to do it correctly.

If this supervision is properly maintained, a large

amount of investigation can be accomplished in connection with the thesis work.

In giving the instruction I have outlined above, it should not be merely class-room instruction, but also laboratory work, partly to emphasize and illustrate the work of the class-room, partly to drill the student in performing carefully and accurately such experimental engineering work as he is liable to be called upon to perform in the practice of his profession, and partly to teach him experimental investigation.

The student will have, of course, in addition to this, laboratory work in his special line, as in the mining laboratory, electrical laboratory, industrial chemistry, laboratory, etc., besides, of course, work in the chemical and physical laboratories.

I have previously called attention to the process of gradual development which has resulted in the extensive introduction of laboratory practice of a variety of kinds into technical instruction, and therefore to the evolution of the engineering laboratories.

As to the organization of such laboratories, the principal objects to be accomplished by them are three, to wit:

(1) To give the students practice in such experimental work as an engineer is constantly liable to be called upon to perform in the practice of his profession, as tests of the strength of materials, evaporative tests of steam boilers, steam engine tests, calorimetric tests, valve setting, etc.; and to teach him to carry on his work with accuracy, and to take all proper precautions to avoid error.

(2) To give the student opportunity of carrying on original investigation in the engineering branches, such as investigations in strength of materials, in steam engineering, etc.

(3) Another important function of such laboratories, which is entirely consistent with the other two, is that of taking up and carrying on systematic investigations of engineering problems, and this can be done in a laboratory, whereas it is only with very great difficulty that it can be

done in a machine shop or a manufacturing establishment.

By publishing these results from time to time the laboratory will serve to add gradually to the common stock of knowledge.

I recognize very fully the incapacity of the student, as a rule, to originate and carry on research without aid from his teachers; but when this aid is given, and the necessary supervision is exercised, a large amount of research can be accomplished in such laboratories.

Original researches should also be carried on by the students in connection with their graduating theses; some of them are, of course, better able to do this kind of work than others, but all should be required to undertake original research, and a careful supervision should be exercised by some one of the instructing force, who should see to it that whatever is done should be properly done, so that the results, as far as they go, whether extensive or not, may be of real value.

Inasmuch as the number of important imvestigations which it is possible to take up and carry out is so very large that only a few can be undertaken in any one laboratory, and, therefore, while there are certain pieces of apparatus of so typical and general a character that all engineering laboratories need them, and should be provided with the best that their means will admit of, as for instance, testing machines and steam engines—the remainder of the apparatus may vary very considerably in equally well-equipped engineering laboratories.

Instead, therefore, of laying down general rules for the equipment and conduct of such laboratories, it seems to me that I shall be better able to convey my ideas by describing to you the equipment of the engineering laboratories of the Massachusetts Institute of Technology, and the way in which they are conducted.

The first attempt at establishing engineering laboratories at the Institute was made in the school year 1873–74, when one was equipped with the following apparatus, viz.:

(*a*) Two horizontal tubular boilers, each 4 feet in diam-

eter and 12 feet long, containing fifty 3-inch tubes; (*b*) one small vertical tubular boiler, 3 feet in diameter, and 7 feet high, containing fifty 2-inch tubes; (*c*) a cast-iron superheater; (*d*) an 8-inch by 24-inch Harris-Corliss engine, with a brake on the fly-wheel; (*e*) a combined surface condenser and calorimeter with the necessary tanks and scales; (*f*) also a variety of accessory apparatus, as indicators, gauges, etc. From this laboratory there emanated an investigation into some special problems on cylinder condensation made for Mr. George B. Dixwell.

From these small beginnings, partly through gradual growth, and partly through considerable changes and improvements made all at one time, have arisen our present engineering laboratories, situated in the Engineering Building, and occupying two floors, 50 x 150 feet each.

The equipment of the Laboratory of Applied Mechanics, *i. e.*, the laboratory for testing the strength of materials, embraces the following apparatus:

(1) A testing machine of 300,000 pounds capacity, made by William Sellers & Company, Incorporated, under the patents of Albert H. Emery, the maker of the Government testing machine of 800,000 pounds capacity at Watertown Arsenal.

This machine has recently been added to the equipment of the laboratory, and it is to be observed that this style of testing machine is the most delicate and accurate in the world. Moreover, the amount of investigation in the line of strength of materials of such a character as to be of positive value to the engineer, which has been made by means of the Government machine at Watertown, is far greater than that which has been accomplished by means of any other testing machine in the world.

It is provided with suitable holders and measuring apparatus to adapt it to specimens of different shapes.

(2) An Olsen testing machine of 50,000 pounds capacity for determining tensile strength, elasticity and compressive strength.

This machine is furnished with compression platforms, which distribute the pressure evenly over the specimen.

(3) A testing machine of 100,000 pounds capacity for determining the transverse strength and stiffness of beams up to twenty-five feet in length. By means of this machine tests are also made on the strength of framing joints used in practice, and on the strength of the riveted joints of plate girders, as well as on other specimens subjected to transverse stress.

(4) A testing machine of 18,000 pounds capacity for determining the transverse strength and stiffness of beams up to fifteen feet in length.

(5) A machine of 144,000-inch pounds capacity for testing the torsional strength and stiffness of shafting up to twenty-one feet in length, provided with apparatus for measuring the angle of twist to four seconds of arc.

(6) A testing machine of 25,000 pounds capacity for determining the strength of ropes or wire, where the clear length of the specimen can be made as great as ten feet. By means of this machine tests are made upon both long and short splices, and on a variety of hitches and holders.

(7) A machine for testing the tensile strength of cements and mortars, where the clips have been specially designed in such a way as to secure an evenly distributed pull on the specimen. In connection with this machine is a complete outfit of nicely-constructed moulds for making the briquettes or specimens, and also all other necessary apparatus, as sieves, tanks, etc.

(8) A machine for determining the strength and elasticity of long specimens of wire.

(9) A machine for determining the strength and elasticity of cloth.

(10) A machine for determining the effect of repeated stresses on the strength and elasticity of iron and steel.

(11) A machine for determining the deflection of parallel rods when running under different conditions.

(12) A quantity of measuring and other apparatus for determining stretch, deflection and twist.

The students who take the subject of applied mechanics in their senior year are required to learn how to use this apparatus, and the method of making the different kinds of

tests, thus learning how tests should be made, and also acquiring a familiarity with the appearance and behavior of materials when subjected to stresses such as occur in practice.

Thus, in the school year each student makes the following tests in the laboratory:

(1) A test to determine the modulus of elasticity, the limit of elasticity, and tensile strength of a cast iron or wrought-iron or steel rod or bar, or the transverse strength of a coupling.

(2) A test of the deflections and of the transverse strength of a full-size iron or steel I beam, or of a wooden beam subjected to transverse load.

(3) A test to determine the modulus of elasticity and the tensile strength of various kinds of wire.

(4) A test to determine the shearing modulus of elasticity and the torsional strength of a shaft.

(5) Tests of the tensile strength of hydraulic cement.

(6) Tests of the compressive strength of hydraulic cement.

(7) Tests of the strength of rope, and the loss of efficiency due to different hitches and knots.

(8) Besides the above the students make a variety of tests of large pieces on the Emery testing machine; sometimes compression tests of full size columns, or of small blocks, or of columns with bolsters, etc., and sometimes tensile tests of pieces of varying shapes and sizes.

The hydraulic laboratory contains:

(1) A closed tank, 5 feet in diameter and 27 feet high, connected with a 10-inch stand-pipe over 70 feet high, so arranged that a constant head may be kept at any desired level.

(2) Apparatus in connection with the tank and stand-pipe, for making experiments on the flow of water through orifices and mouth-pieces, over weirs and in pipes, under different heads and conditions, and on the losses of head occurring under different circumstances.

(3) A system of pipes, connected both with the main pipe and with the pumps, is fitted for the insertion of diaphragms, branches and other apparatus for studying loss of head and the laws of discharge.

(4) An attachment to the main tank, containing a Pitot tube for studying the laws of velocity in jets, and adjustable points for the measurement of the cross-section of jets.

(5) A cylindrical steel measuring tank of 280 cubic feet capacity.

(6) A six-inch Swain turbine, so arranged that it can be run under different heads, and that measurements can be made of the power exerted, of the efficiency, etc., under different gates.

(7) A 48-inch Pelton water motor, similarly arranged.

(8) A Venturi meter and numerous hose nozzles for measuring water.

(9) A weir of adjustable width up to four feet.

(10) A hydraulic ram with a two and one-half inch drive pipe.

The steam laboratory contains:

(1) A triple-expansion engine, with cylinders of 9 inches 16 inches, and 24 inches diameter, respectively, by 30 inches stroke, arranged in such a way as to be run single, compound or triple, as desired for the purposes of experiment. It is of the Corliss type, and has a capacity of about 150 horse-power when running triple, with an initial pressure of 150 pounds in the high-pressure cylinder. To it is connected a surface condenser, and the other apparatus needed to adapt it to the purposes of accurate experiment.

The ends and barrels of the cylinders are separately jacketed, so that steam can be let into either or both. The receivers are also jacketed so that they can be used either with steam in the jackets or not. The cut-off on all three cylinders can be thrown into connection with the governor, or any of them can be disconnected from the governor and adjusted by hand at a fixed point. Cans are provided for catching the drip from each jacket, and these cans are provided with water-glasses so that we can determine its quantity.

The engine is thus fitted to carry on series of experiments under different conditions, and by its use we can obtain results comparable with the results that are actually realized on large marine and stationary engines. The water consump-

tion per horse-power per hour varies with the different conditions under which the engine is run, but we have found it under some conditions as low as 13·7 pounds.

A very considerable amount of investigation has been carried on already, and valuable results have been obtained.

(2) A Harris-Corliss engine, with cylinder 8 inches diameter by 24 inches stroke, with a capacity of about 16 horse-power, with an initial pressure of 75 pounds. This engine is also connected with a surface condenser and a tank on scales to weigh the condensed steam, and, of course, it can be used to make engine tests; but inasmuch as it is a small engine, it is not economical, using from 30 to 40 pounds of water per horse-power per hour; and, now that we have the triple expansion engine, we use the Harris-Corliss machine mainly for valve-setting. Moreover, this Harris-Corliss engine is the original one that was put in the laboratory when it was first founded, in 1873, by means of which the investigations were made for Mr. Dixwell.

There is also another eight-horse-power engine used for valve-setting, etc.

(3) Of surface condensers there are four in all: (*a*) the one connected with the triple-expansion engine, and which is also specially arranged for experimental purposes in such a way that the condensing water can be made to pass once, twice or three times the length of the condenser while performing its functions; (*b*) a smaller surface condenser attached to the Harris-Corliss engine, and (*c*) and (*d*) two other surface condensers, used in various experiments.

(4) A mercurial pressure column which extends to 160 pounds pressure, by means of which our gauges are tested. There is also a mercurial vacuum column.

(5) A dynamic steam engine indicator tester.

(6) Several pieces of apparatus for determining the quantity of steam issuing from a given orifice, or through a short tube, under a given difference of pressure.

(7) Apparatus for testing steam injectors.

(8) A number of steam pumps, the largest one being a duplex pump 16, 10½ by 12 inches.

(9) A number and variety of calorimeters.

(10) A large supply of indicators, planimeters, gauges, thermometers, anemometers and other accessory apparatus.

(11) There are in the different buildings two 208-horse-power sectional boilers, two 100-horse-power, and one eighty-horse-power horizontal tubular boilers, and another sixty-horse-power horizontal tubular boiler at the shops, and these are used for making boiler tests; all the fourth year students of mechanical, electrical, chemical engineering and naval architecture, having to take part in these tests.

It is believed that the students can best learn to make boiler tests by making them on large boilers producing a considerable quantity of steam.

Besides all the above, the engineering laboratories are provided with several friction brakes of different capacities; with machinery for determining the tension required in a belt to enable it to carry a given amount of power, at a given speed, with no more than a given amount of slip; with a machine for testing the transmission of power by ropes; with a number of transmission dynamometers; with a four-horse-power gas engine; with a complete set of Westinghouse air-brake apparatus, including the parts belonging to the car and to the locomotive; with the pump and engineer's valve of the New York air-brake; with a measuring tank for large quantities of water, this tank being provided with a number of orifices in the bottom, and a water glass on the side; with a number of water meters, and of weirs of different sizes, for measuring water; with a locomotive link model; with a centrifugal pump, a gang pump and a rotary pump; with a hot-air engine; with a pulsometer pump; with an experimental governor; with an oil-testing machine; with a number of water motors; with an ejector; and with cotton machinery as follows: two cards, a drawing frame, a speeder, a fly frame, a ring frame and a mule, as well as accessory apparatus. As to the work required of the students of mechanical, electrical and chemical engineering, I will say that in the second term of their junior year they are required to make, under careful supervision, engine tests on the triple engine. In the course of the senior year the list of tests made by each student is approximately as follows, viz.:

Tests of the transmission of power by belting; test of the performance of a surface condenser; test of a direct-acting steam pump; test of the flow of steam; valve setting (plain slide valve); test of a pulsometer; test of a plunger pump; calibration of orifices for the flow of water; determination of the clearance of an engine; use of the different dynamometers; valve setting (double valve); testing gauges by means of the mercury column; test of some of the boilers; test of the steam injector; test of steam ejectors; use of the different kinds of calorimeters; test of a Swain turbine; measurement of the flow of water by means of orifices and weirs; test of water motors; test of a hot-air engine; valve setting (Harris-Corliss engine); analysis of chimney gas; test of a battery of boilers application of Hirn's analysis to the triple-expansion engine in the laboratory; test of the efficiency of a Weston differential pulley block; test of the efficiency of jack screws (each test is performed by a squad of from two to five students, and the results are then worked up and handed in within two or three days by each member of the squad); test on experimental governor; tests on the indicator tester; tests on the gas engine; tests of water meters; calibration of hose nozzles, etc.

The tests are all made under such supervision as will insure accurate work, and reliable results.

Then each student is required to make all the calculations for every test in which he takes part, and to hand them in within a week.

These reports are examined by competent instructors who make all the calculations independently before examining those of the students.

Then each student is furnished with the results of all the tests in which he takes part, and, moreover, the results of the investigations made in the course of the regular laboratory work of the engineering laboratories is regularly published in the *Technology Quarterly.*

The above is a description of the equipment of, and the work done in, these laboratories at the Massachusetts Insti-

tute of Technology. It is plain that some of the most common work of the engineer in practice will be to make tests of steam engines and of steam boilers, to make tests of power and to determine quantities of water either in hydraulic work or in work on steam.

Now, the young engineer should be drilled in doing this work accurately and well, and should understand what constitutes good work; more especially is this of importance because there are so many so-called engineers who make tests carelessly and publish results which have been obtained from tests erroneously made. Too often they do not give a detailed description of how they made their tests. Before one can judge of the credibility of the results of a test, he needs to know how the test was made.

The student should be taught to do all that he does, well and thoroughly. It will be easy enough to teach him to do rough work when it is required if he knows how to do accurate work, but if he is accustomed to do rough work it will be very difficult to make him do accurate work.

WATER PURIFICATION.*

By Rudolph Hering.

The subject of the lecture which has been set down for to-night is one which might occupy our time for many evenings, even if it should be treated, in part, quite superficially. There are many aspects under which it might be considered, and, in order that it may possibly be of some value to you, it is necessary that we confine ourselves to but one aspect, and even this one we shall not be able to exhaust.

The use of water may be divided into three general classes—domestic, public and manufacturing. In the first class we place the water used for drinking, for cooking and for washing; the second class comprises the water used in

* A lecture delivered before the Franklin Institute, February 2, 1894.

fountains, for extinguishing fires, for street-cleaning, sewer flushing and the like; and the third, the water required for different industries.

It is evident, therefore, that the water supplied to a community for these various purposes might properly have different degrees of purity. The highest grade of purity is required for domestic purposes. If there is a sufficient quantity having this high quality available to supply all the uses to which water may be put in a city, so much the better; if such a source is limited, then we must avail ourselves of different supplies for the same city. Such is the case, for instance, in the cities of Paris and Vienna.

We shall confine ourselves, in the following, to water required for a domestic supply; namely, to that which should be pure in a sanitary sense, and which may be used for drinking, cooking, etc.

Such water should contain no foreign matter which is known to produce an injurious effect upon the human body, or which, with good reason, is suspected of producing such an effect, and it should be pleasant to the taste. It should also be, as far as practicable, free from all substances and associations which may offend the general æsthetic sense and affect the system through the imagination, even though the water itself be perfectly harmless.

We may therefore say that water which is suitable for domestic uses must be clear, cool, soft, without odor and with but a slight taste, neither stale, salty nor sweetish. It should have air in solution, it should contain but little foreign matter, and, most important of all, it should contain no pathogenic or sickness-producing microbes.

It may, with advantage, contain certain mineral salts, particularly a little lime, to supply nourishment for such parts of the body as require mineral matter. Among the salts of lime, the stomach takes more kindly to the carbonates than to the other compounds. Further, an excess of carbonic acid in drinking water aids the digestion of certain fluids which otherwise might be harmful; but, on the other hand, it is not desirable for cooking purposes. When drinking water has a disagreeable taste and a high temper-

ature, it will, as a rule, diminish the secretion of gastric juices and cause a poor digestion.

Water without air in solution may be quite harmless to drink, but in natural waters such absence may indicate other dangerous qualities, inasmuch as the air may have been absorbed by the decomposition of organic matter in the presence of dangerous microbes.

In water used for washing, salts of magnesia are objectionable, on account of the hardness which they produce. They also act as a laxative and are therefore debilitating. Hard water fatigues the intestines, and injures the assimilative processes by forming insoluble compounds with some food materials. Water containing an excess of salts may even counteract the digestive processes and favor hurtful molecular actions. All sulphates will generally lie heavily in the stomach. Nitrates are not injurious of themselves, but their presence in water may indicate a previous sewage pollution, and therefore a danger possibly still existing.

Finally, a water contaminated with organic matter may bring into the system microbes, or bacteria, and ferments, which interfere with the normal functions of the stomach and the intestines. After entering the body they may cause sickness to a more or less serious degree. Most dangerous of all is a pollution by those bacteria which are the cause of some of our most fatal diseases. Cholera bacilli, which were introduced into the drinking water of Hamburg, caused the late epidemic in that city, the most recent warning of the danger of such pollution. The epidemic of typhoid fever in Plymouth, Pa., some years ago, was caused by the introduction of typhoid bacilli from a single individual into the limpid waters of a mountain brook supplying a part of the city. Within a few weeks over 1,000 cases of typhoid fever occurred among the water-takers of that otherwise healthful town, and of these cases over 100 were fatal.

There are already on record so many cases showing the unmistakeable connection between the water of a domestic supply, polluted by certain species of bacteria, and the appearance, among the consumers of this water, of the

disease associated with such organisms, that it should now be considered almost criminal to ignore any practical means for obviating the recurrence of such calamities, and for maintaining a pure supply.

In addition to guarding the sources against pollution, we must also guard the water itself after it is in our midst. If pure spring water or ground water is brought to rest in an open reservoir exposed to light and warmth, living organisms rapidly develop therein. The atmosphere has supplied the germs, and warmth and light have caused them to multiply. A green scum covers the water, and later it is filled with algæ and bacteria, until the organic matter which serves as a food has been completely removed. River water, stored in a similar manner, is generally not so altered, because the conditions of storage are not materially different from those in the river, and there is no cause for a sudden change in the action of the bacteria. Therefore, when the water comes from springs or from underground sources, it must, to keep it pure, be stored in *covered* reservoirs.

But even this precaution does not always protect it, for it is difficult to preserve in all respects the same conditions which existed at the source. We have on record a case which well illustrates this. The supply of Monaco comes entirely from springs. At the covered reservoir it arrived with five microbes per cubic centimeter. After twenty-four hours there were several hundred, and after a week over three hundred thousand, or sixty thousand times as many as at first. After standing, the number of microbes decreased, until, being after six months in the same reservoir there were found to be but ninety-five per cubic centimeter.

This curious fact, that spring water when exposed to the atmosphere will cause a greater development of bacteria than river water, is noticed also in the relation between sterilized and non-sterilized water. In the former, when sterilized by boiling, it was found that typhoid bacilli continued to flourish vigorously for three months, while in the same water, which had not been boiled, they gradually disappeared.

Water brought to a city in a pure condition, or sterilized

at home, should therefore be used as soon as possible, and before it can receive fresh bacteria from the air.

Muddy water should not necessarily be condemned, if turbidity is its only objectionable feature. While a clear water, is of course, more desirable, a turbid source should not weigh against the adoption of one that is comparatively free from dangerous bacteria, for muddy water free from pathogenic or disease-producing microbes is far preferable to clear water containing them.

If much vegetable matter is contained in the water it may be unwholesome. Water from marshes is known to have caused intestinal derangements and probably also malarial and other fevers.

Animal matter produces a still more dangerous effect, and it is to-day believed that most of the zymotic diseases are caused indirectly by animal pollution of water supplies.

Water which contains organic matter, if left standing in a vessel in a warm place, gradually becomes turbid, and after a certain time a film may be seen on the surface, while deposits form on the sides and on the bottom. Sometimes certain offensive gases escape. The turbidity is caused by myriads of microbes which are living on the organic matter contained in the water.

All waters used for domestic purposes are more or less liable to pollution by microbes which may be injurious to persons whose temporary or chronic condition of health may not be good. It is, therefore, the first duty of the engineer who is to select a source and design works for supplying a community, to consider only those waters which are naturally healthful at the source, or those which can be artificially made so at a reasonable expense. While, however, artificial purification may accomplish all that seems to be required, yet, when there is a choice, preference should always be given to water from the purer source.

We shall now refer to the different known methods of artificially purifying waters in a sanitary sense.

Water may be thoroughly purified, or, we should rather say, sterilized, by the process of *boiling*, which, if continued long enough, will destroy all living organisms contained in

it. This safeguard is the one usually resorted to in the household when the city water is suspected. The length of time necessary for boiling has been very differently stated by different authorities. Professor Tyndall found that there are certain stages in the life of bacteria when they can resist the action of boiling water, but these stages are of short duration, and, according to his statement, if boiling is continued for several hours, it will permanently destroy every vestige of life. Other authorities give twenty minutes as a sufficiently long time to render the water harmless.

Another method of artificial purification is the *aëration* of water. It has been the common belief that water, when it is deprived of air, deteriorates and becomes unfit for use, but the waters of deep springs, which have a high degree of purity, sometimes contain no air. Water exposed to air dissolves some of its constituents, viz: oxygen, nitrogen and carbonic acid. When the water contains organic matter, a change takes place, and the absorbed oxygen causes an oxidation of the organic into mineral matter. This oxidation, however, is almost entirely effected by the activity of living bacteria. The carbon and nitrogen of the organic matter combine with the oxygen. It has been thought that mechanical aëration would hasten the process of oxidation, but as this can be accomplished only by increasing the number of bacteria, or by providing more favorable conditions for their activity, the belief in purification by artificial aëration has begun to vanish.

Experiments that have been made on this subject have directly shown that oxidation of organic matter in water, is not hastened by vigorously agitating it with air, even when air is introduced into it under pressure.* But the aëration of water may still serve a useful purpose. It will prevent stagnation by supplying the usual amount of oxygen, and, for the same reason, will prevent the growth of algæ therein. It will also remove disagreeable gases which may arise from stagnant waters, and finally it serves a useful purpose in certain waters containing iron in solu-

*"The Effect of the Aëration of Natural Waters." By Thomas M. Drown, M.D., Chemist of the Massachusetts State Board of Health.

tion, by oxidizing the iron and thus rendering the water more palatable.

Dr. Frankland, in London, has lately shown that a partial purification of water may be obtained by *agitation* with certain materials in a fine state of division, and allowing a subsequent sedimentation.* His experiments with coke and charcoal were especially effective. Water, agitated with one-fiftieth of its weight of finely-powdered coke, was found, after settling, absolutely sterile, that is, without a single organism.

A method of purification which may be discussed under this same head has lately been brought into prominence by Mr. Anderson, who has patented a process for agitating water with small particles of iron in a revolving cylinder. He had before noticed the purifying effect of passing water through spongy iron, but, as this soon became useless by the clogging of its pores, he conceived the idea of having small bits of wrought or cast iron dropped through the water, instead of causing the water to pass through the pores of the iron. This is done by a simple mechanical operation in a revolving cylinder. Through the agency of carbonic acid contained in the water the iron is converted into ferrous carbonate, which is partly dissolved and partly suspended in the water, and gives it a slightly greenish hue. When acted on the air contained in the water, the iron is converted into ferric oxide, which first coagulates the organic matter held in suspension, and then acts as a precipitant in carrying down with it, as it settles, the fine particles held in suspension. The water is subsequently filtered in order to remove the sediment caused by the iron and its included impurities.

An examination of water so treated shows that no iron has been left in it, and that the precipitate has freed the water from a very large proportion of the bacteria originally contained in it. The high degree of purity, however, which is claimed as a result of this process of agitating the water with iron, is due largely to the subsequent sand filtration.

*"Water Purification : its Biological and Chemical Basis." By Percy F. Frankland, Ph.D., etc., a paper read before the Institution of Civil Engineers.

Dr. Frankland has more recently made experiments to ascertain the value of *sedimentation* alone, without any addition of coke, charcoal or iron. He found in a number of cases that raw river water running into a reservoir in London contained from five to ten times as many bacteria per cubic centimeter as the water running out of the same.* It may, therefore, be of great economical importance that sedimentation should be allowed to take place before resorting to more expensive methods of purification, for the former process may reduce the extent to which the latter need be carried.

Another method of purifying water is the direct *precipitation* of the objectionable matter by the addition of chemicals, generally in solution. These form, with portions of the organic matter, insoluble compounds, which, in gradually descending to the bottom, carry with them the suspended matter, be it organic or mineral.† The result, therefore, is a clarification, and, to some degree, also, a purification, of the water.

The chemicals which are added to water for the purpose of precipitation, are generally lime, salts of alumina, or salts of iron. They cause a coagulation of the organic matter, forming flocculent masses throughout the water.

While the precipitation processes serve at times an excellent purpose, we should not forget that the resulting water, though clear, may not be pure. It is true that a very large number of bacteria is carried down with the descending flocculent matter. Experiments have shown that 98 per cent. of the original number may thus be removed. It is seldom, however, that more than one-half of the entire organic matter is precipitated from the water, and more than three-quarters of the number of bacteria, and thus the water may again become objectionable through the develop-

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* "The Purification of Water by Precipitation and Sedimentation." A letter written by Dr. Percy Frankland, F.R.S., to "Industries and Iron," December 8, 1893.

† They also carry down a large percentage of the bacteria. If, however, the water is allowed to stand long, the organisms first carried down will rise again and be distributed through the water.

ment of fresh bacterial life in the organic matter which is not removed.*

Lime is extensively used for precipitation, particularly when water is very foul. It readily coagulates organic matter, and, in quantities merely sufficient to effect a clarification, does not injure the water, because all of the lime generally sinks to the bottom. It is rarely necessary to use more than a half a grain to the gallon of water.

The action of alum is similar, so far as the method of purification is concerned, but it has the additional advantage of combining with coloring matter, and thus causing the water to become clearer than when lime alone is used. When water contains carbonate of lime in solution, the addition of alum causes the formation of sulphate of lime, carbonic acid and hydrate of alumina. The sulphate and the carbonic acid remain dissolved in the water, while the alumina forms a gelatinous or flocculent mass, which, as it settles down, drags with it the suspended matter which causes the turbidity. The alumina also forms insoluble combinations with some of the dissolved organic matter, and this is also precipitated. The amount of alum necessary to give perfectly clear water ranges from one-half grain to five grains per gallon. Too much alum will make the water acid and thus cause it to rust all iron with which it comes in contact. When a smaller quantity will not properly precipitate all the suspended matter, it is of advantage to add a small amount of lime sufficient to neutralize the acid developed by the alum.

The Chinese and other Asiatic people have long been familiar with this effect. They put a piece of alum into a hole in the end of a bamboo stick. The water is first stirred with this stick and is then allowed to settle.

Salts of iron are likewise excellent precipitants and, for some waters, are preferred to alum and lime. Ferric oxide is especially efficacious when in a nascent state, as already

* "Report of Experiments upon the Chemical Precipitation of Sewage," made at the Lawrence Experiment Station during 1889. By Allen Hazen, Chemist in charge at the Station. Massachusetts State Board of Health. 1890. Vol. II. Pp. 737–91.

mentioned when speaking of the process of purifying water by means of small particles of iron. The coagulated ferric hydrate, in settling through the water, removes most of the bacteria contained therein.

Ferric sulphate and per-chloride are also used to coagulate the organic matter, but they are more expensive, and their action upon drinking waters, is less favorable than that of the substances already mentioned.

It has already been mentioned, under the head of sedimentation, that charcoal and coke, when finely divided, carry down much of the suspended matter. Finely divided clay, when in suspension, as in our western rivers, will act in a similar way, and thus, if their turbid water is allowed to rest, will carry down the major portion of the impurities.

Before we leave the subject of precipitation, we must mention a process which quite recently has been much discussed, viz.. the purification of water by electrolysis. Electricity is employed to produce a decomposition of the salts contained in solution and to transform into harmless compounds the organic matter contained in the water. When an electric current is passed through water containing chlorides, for instance common salt, these are gradually converted into hypo-chlorites, which destroy organic matter brought in contact with them. We are all familiar with the action of hypo-chlorite of lime, which is very commonly used as a disinfectant. By adding salt to water, or by using sea water, a hypo-chlorite of soda is formed which precipitates the organic matter and promptly destroys it by oxidation.

How far this process may be made available for the purification of drinking water is yet a question. At the present time, so far as I know, it is used only for the purpose of purifying a stream containing the sewage of Brewster, in the water-shed supplying the city of New York with its drinking water, and there only upon a small scale.

[*To be concluded.*]

NOTES AND COMMENTS.

ANNUAL REVIEW OF SCIENCE AND INDUSTRY.*

The production of crude iron is properly regarded as a fairly accurate barometer of the state of general trade and commerce. The figures of the year's production, accordingly, which have just been issued on the authority of the American Iron and Steel Association, reflect the pronounced depression in business which characterized the greater part of that disastrous period, viz.: the total production of pig iron in 1894 was 6,657,388 gross tons, against 7,124,502 tons in 1893; 9,157,000 tons in 1892; 8,279,870 tons in 1891; and 9,202,703 tons in 1890. The production in 1893 was 2,032,498 tons, or over 22 per cent., less than in 1892; and the production in 1894 was 467,114 tons, or over 6½ per cent., less than in 1893. The production in the first half of 1894 was 2,717,983 tons, and in the last half of 1894 it was 3,939,405 tons. The total production of pig iron in 1894 was the lowest yearly production since 1888.

The number of furnaces which were in blast on June 30, 1893, immediately after the panic of that year, was 226; by December 31, 1893, the number in blast had fallen to 137; on June 30, 1894, there were only 108 in blast; on December 31, 1894, the number in blast had increased to 185.

A glance at the transportation interests will show that the falling off of traffic during the year 1894, has had no parallel in the experience of the present generation. The enormous losses of income thus entailed have not only told severely against a large number of unfortunately situated or over-capitalized railway companies, forcing many of them into bankruptcy—but have also operated in placing a decided check upon railway extensions in almost every section of the country; and indirectly, by reason of the severe economies which these losses have enforced upon all alike, they have checked the demand for railway materials and supplies to an extent which even the most pronounced pessimist would scarcely have believed possible at the close of 1893. Rail-makers, locomotive-, car- and bridge-builders, accordingly have suffered alike, as the following brief statistical statements will demonstrate:

Some weeks must elapse before the complete record of new railroad construction will be available, so that we must be satisfied at this time with estimates, which may be accepted as approaching closely to accuracy. I present, accordingly, on the authority of the *Railway Age*, the following figures of the probable mileage of new railroad constructed last year. For the United States the new construction is estimated to have been 1,919 miles, and the significant comment is made that these figures are the lowest of any for the last twenty years. In the last five years the new mileage was respect-

*An abstract from the report of the Secretary to the stated meeting of the Institute, held January 16, 1895.

ively: In 1890, 5,670 miles; in 1891, 4,282 miles; in 1892, 4,178 miles; in 1893, 2,635 miles; in 1894, 1,919 miles.

* * * * The diminished figures of steel rail production have their explanation in the condition of things here exhibited. * * * * In locomotive building the same story is repeated. The *Railroad Gazette* estimates that the decrease in the number of locomotives built was nearly two-thirds as compared with the previous year. Reports from thirteen companies, which built 2,011 locomotives in 1893, give their output in 1894 as 695. The exhibit made by the car- and bridge-builders is even worse, but I will not weary you with the details. It is gratifying, in passing from these disheartening proofs of extreme industrial depression, to note the very general belief that the worst effects of this depression have been felt, and that the present year will witness the slow but steady return of the country to prosperous conditions.

* * * * An engineering work, which was begun in 1892, and which promises to have important results for the city of Chicago, was considerably advanced towards completion during the past year. I refer to the great Chicago Canal, which, when finished, will establish communication between the waters of the Great Lakes and the Gulf of Mexico. The general character of this undertaking is given in the following extract from the *Scientific American:*

"The headwaters of the Des Plaines River lie in Wisconsin, near Lake Michigan. The river runs to the south approximately parallel with the western shore of the lake, and, after it has reached the parallel of Chicago, trends to the southwest, and, passing through Joliet, joins its waters with those of the Kankakee River, forming the Illinois River. The combined waters run through the channel of the Illinois River to the Mississippi, emptying into it a short distance above the mouth of the Missouri River. Through the city of Chicago winds the small stream called the Chicago River, a devious creek with several branches. This enters into the lake. A distance of a little over ten miles intervenes between the lake shore and the Des Plaines River at Chicago, while between the Chicago River and Des Plaines River but two miles intervenes. At present much of the sewage of Chicago runs into the lake, threatening with contamination the water supply of the city, notwithstanding the fact that the intake of the water works is situated some miles out in the lake. Largely to avoid this contamination, the great drainage works have been undertaken. * * * *

"At Chicago there is a true divide, the waters on the east pouring into Lake Michigan, and on the west reaching the Gulf of Mexico, through the channels of the Des Plaines, Illinois and Mississippi Rivers. Should the divide be pierced, the waters of Lake Michigan would run into the Gulf of Mexico as well as into the Gulf of St. Lawrence, and an internal waterway, from the British Provinces through the St. Lawrence and the Great Lakes to the Gulf of Mexico, would be created. At present work is being done on this connection, and if all goes well, by 1896, the city of Chicago will have internal water communication with the Gulf of Mexico—which she will be able to utilize for the transportation of freight, as well as for the disposal of her sewage."

The estimated cost of this work is about $22,000,000, and it is being carried on (principally) by the State of Illinois, with partial aid of the Government. The date set for the probable completion of the canal is November 1, 1896.

The much-mooted suggestions for enlarging and improving the canal routes connecting New York with Philadelphia and Chesapeake Bay, are gradually assuming definite shape, and there is now a reasonable prospect that this work may soon be accomplished. These improvements are much needed, and the expense incurred will doubtless be justified by the consequent increase of commerce. I quote substantially from the *Scientific American* the following information bearing on the subject:

"The city of Philadelphia some months ago appropriated $10,000 to be expended in making preliminary surveys and maps preparatory to enlarging the Delaware and Raritan Canal, and this has been followed by the appropriation of a like amount by the city of New York, for the same purpose. In addition to this a bill is now before Congress, having already passed the House of Representatives, providing for the appropriation of a sufficient sum of money to commence the actual work. Plans are also under discussion to enlarge and extend the Dismal Swamp Canal and the Albemarle and Chesapeake Canal.

"The latest report of the surveyors of the Delaware and Raritan Canal stated that the full length of the proposed new route would be thirty-two miles. The surface elevation along this route is higher than in the case of the old canal, but it will probably be selected because it saves the building of two expensive overhead bridges. The new canal will then start from Raritan Bay, cross the Raritan River about eight miles below New Brunswick and enter the Delaware River at Bordentown. Eleven miles of its length will be an enlargement of the old canal. The other twenty-one miles will be an original excavation. It will have a depth of 24 feet, a bottom width of 90 feet and a surface width of 160 feet. It will be provided with two opening locks 500 by 60 feet, and four lift locks with a total lift of 50 feet. The entire cost has been estimated at $12,500,000. Of this amount $50,000 will be expended in deepening the channel of the Delaware River between Philadelphia and Bordentown.

"It is, furthermore, proposed to make connections with the Dismal Swamp Canal, and to widen and deepen this canal in a similar way. The Dismal Swamp Canal commences at Deep Creek, Norfolk, Va., and extends in a southerly direction to South Mills, N. C., near the head waters of the Pasquotank River, which empties into Albemarle Sound. The canal proper is 22 miles long and 60 feet wide, and is provided with five locks. It has an average depth of 8 feet. It extends from deep water to deep water. An enlargement is being planned. It is proposed to give it an average depth of 10 feet and provide two locks, one at either end, to be 250 feet long and 40 feet wide. The estimated expense of these improvements will be $5,000,000.

"The Albemarle and Chesapeake Canal connects the waters of the southern branch of the Elizabeth River, which has its mouth at Norfolk, with the North Landing River and North River. The canal is 14 miles long

and has an average depth of 8 feet. The present owners propose to enlarge this to about the size of the others, so that large ships may pass through the entire system."

The approaching completion of the Canadian Sault Ste Marie Canal is an event worthy of notice, from the fact, as the *Iron Age* points out, that it will constitute practically the last link in a chain of waterways on Canadian territory that has cost the debt-burdened Dominion over $67,000,000, and which, at no distant day, will allow ocean vessels passage to the northern lakes. There are still to be completed some unimportant links on the lower St. Lawrence, which, however, will entail no serious additional outlay. When it is considered that, of the present enormous traffic of the old Sault Canal (on the American side), and which, in 1893, amounted to 10,796,000 tons of freight carried in 12,800 vessels, and valued at $146,500,000, only five per cent. was in Canadian vessels, the conclusion is obvious that the object of these vast expenditures is to make the Dominion of Canada independent of the United States in the possession of its own highway to and from the northern lakes and the ocean.

Incidentally, it may be of interest to call attention to the fact that the traffic of the present American canal for the past few years has exceeded that of the Suez Canal. In 1893, for example, the tonnage passing the latter was 7,650,000, or 3,000,000 tons less than that passing through the former.

The contracts for a notable engineering work were given out at the close of the year by the New York and Long Island Bridge Company. The company proposes to erect a bridge across the East River from Sixty-fourth Street, New York, by way of Blackwell's Island, to Long Island. The structure, as planned, will be a four-track railway bridge, having two main channel spans of 846 feet each, with a span over the island of 613 feet, and cantilever arms at the ends of 192 feet, which would make the total length of the bridge proper 2,689 feet. The New York approach will be about 2,000 feet long, and the Long Island approach about 5,000 feet. Including the approaches, therefore, the structure will have a total length of 9,690 feet. About 50,000 tons of steel will be required in the superstructure.

The bridging of the Hudson River, at New York, has been seriously proposed, and the Government engineers have sanctioned two propositions, one for a cantilever structure with two river piers, and the other for a suspension bridge. Both of these contemplate a structure having clear headway of 150 feet, so as to constitute no impediment to free navigation. The estimated cost of these enormous bridges is $23,000,000 and $35,000,000, respectively. The consensus of engineering opinion respecting the relative merits of these plans favors the cantilever structure.

The necessary preliminary concessions have been granted for the construction of a railroad bridge over the Delaware River from a point below Bridesburg on the Pennsylvania side, to Fisher's Point, on the Jersey shore. The bridge is to be constructed by the Pennsylvania Railroad. The plan approved by the Government engineers and the City Councils is as follows: The approach of the Pennsylvania side will begin at Frankford Junction, on the New York Division of the Pennsylvania Railroad, and will connect

with the Camden and Amboy Railroad at Fish House Station, on the New Jersey side. The bridge will be 1,950 feet in length, and will have a double-track line of railroad, to be built at a clear height of fifty feet above high water. The width will be thirty-four feet over all. It will be constructed of steel and will be supported by six piers of masonry, rising fifty feet above the water. The bridge will have three fixed spans, 540 feet in length, and a draw span of 330 feet over all, providing for two clear openings of 125 feet each in the river channel. The piers under the fixed spans will be built of granite, sixty-seven feet long and twenty-one feet wide, standing forty-five feet in height above high water. The approach of the bridge on the Pennsylvania side of the river will be two miles in length, and on the New Jersey side one-half mile in length.

The Philadelphia Trades League, it may be noted, has filed a protest with the Secretary of War against the construction of the bridge on this general plan, on the ground that a structure with so small an elevation as fifty feet would form a serious obstacle to the navigation of the river, and would greatly diminish the value and check the future development of the nearly five and a half miles of river front within the city limits above the site of the proposed bridge. To avoid this serious objection, the Trades League asks that the height of the bridge be made seventy feet instead of fifty feet.

A commission has been appointed by the French Government to examine and report upon the feasibility of a scheme for a ship canal to unite the waters of the Atlantic with those of the Mediterranean Sea. The route of the proposed canal would cut across the neck of land joining the great Spanish Peninsula with the mainland; the termini of the line would be, respectively, Bordeaux on the Atlantic and Narbonne on the Mediterranean. This canal, if of sufficient size to accommodate ocean-journeying steam vessels, would cut off about two-thirds of the distance from the English Channel to Suez, as compared with the present sea route skirting the Bay of Biscay and the coast of Spain, since vessels from the North Atlantic to the Mediterranean and *vice versa* would be able to make the short cut through the canal instead of going around the coast of Spain. It is interesting to note that this is the third time that this project has been made the subject of investigation by the French Government, the persistance of its advocates being due most probably to the belief that the canal would afford the advantage of giving the vessels of the French Navy a passage either into the Atlantic or the Mediterranean without running the gauntlet of Gibraltar. Two commissions have already reported the project to be impracticable, on the ground of excessive cost of execution.

* * * In the field of electrical engineering, by far the most interesting enterprise is that of the Niagara Falls Power Company, with the general character of which you are all familiar. The problems to be solved in connection with the electric transmission have involved the most exhaustive and painstaking studies of theoretical questions connected with the design and construction of generators to insure the selection of the type and system of transmission which will realize the highest practical efficiency. In the determination of these questions the opinions of men of the highest scien-

tific repute were sought and obtained, and the result of these very thorough preliminary inquiries will shortly be apparent.

The great power-house is now complete, the turbines and vertical shafts up to the floor of the power-house have long been in place, and the three great dynamos of 5,000 horse-power each, built by the Westinghouse Company, from the designs of Prof. George Forbes, are finished and ready to be finally put in place.

It is stated that the first plant to be supplied with current from the Niagara installation will be the aluminum manufactory of the Pittsburgh Reduction Company—the owners of the Hall patents for the electrolytic production of the metal from a bath of fused fluorides, in which the oxide of aluminum is dissolved. For the purpose of this manufacture, the 2,000 volts two-phase alternating current generated by the Power Company's dynamos, requires to be converted into a continuous current of 160 volts, which is accomplished by transformers applied in a novel manner. The company will begin operations with an available supply of 2,000 horse-power, and should then be able to supply the numerous and growing demands of the industries for aluminum at prices low enough to admit of its use on a far more extensive scale than has hitherto been permissible.

The Carborundum Company, also, has made arrangements for using 1,000 horse-power. This company, it will be remembered, manufactures a compound of carbon and silicon by the electric furnace method, and the product, though the fruit of a comparatively recent discovery, has already assumed an important place in the arts, as an abrasive material.

Other enterprises of similar character, although of less magnitude, are under way. Of these, a notable one is the electric power transmission plant at the falls of the Willamette River, near Portland, Ore., where a great long-distance transmission is being installed. This plant, when completed, will employ twenty electric generators, each of 600 horse-power, and capable, therefore, of delivering the total amount of nearly 12,000 horse-power to Portland, eleven miles distant. A similar project for supplying 4,000 horse-power to the city of Sacramento, Cal., from a water-power situated about twenty-five miles distant, is approaching completion. The preliminary steps are being taken for the construction of an electric power transmission plant to utilize the water-power of the Susquehanna River. The plan is fathered by a corporation called the Susquehanna River Electric Company, and contemplates the damming of the Susquehanna River near Conowingo, Md., and the erection of a large electric power-house, similar to the one at Niagara Falls. The power obtained in this way will be supplied to Philadelphia, Wilmington and Baltimore, and other intermediate points. It is expected that it will be used extensively in operating street railways and electric lights. The land at the proposed site of the dam has been purchased, the surveys have already been made, and the plans have been made for an immense plant. It is announced that this work will be started in the spring of the present year. Other projects of like character are being industriously mooted in the electrical journals, and it will need only the encouragement of success in the several undertakings now approaching completion

to bring a number of others to the fore. It remains only to be added that the advances that have been achieved within the past few years in the solution of questions of dynamo construction, have radically changed the aspect of the problem of electric power transmission, and it is now reasonably safe to predict that we are on the eve of a departure from the existing order of things which may profoundly affect our present social and industrial conditions.

The past year witnessed a remarkable extension of the overhead trolley system, not only for city and suburban service, but also on long-distance lines. The most noteworthy of those extensions probably was made in our own city, where the completion and starting in operation of a great network of surface electric railways has taken place. A similar transformation has been made in the street railway systems of Baltimore and New Orleans, and the projects for long-distance electric railways that are under consideration, or in course of completion, are too numerous to mention. Thus, for instance, only a few links are missing in a continuous chain of trolley lines between Philadelphia and New York; while trolley service between Philadelphia and Harrisburg, Baltimore and Washington, Chicago and Milwaukee, will doubtless be established during the present year.

While on this subject, the experimental work undertaken in New York by the Metropolitan Street Railway Company in the development of a satisfactory underground electric conduit system adapted for city service, is worthy of mention; also, the fact that an extensive underground electric system is about to be constructed in Washington. In Chicago, work is well under way on a complete elevated electric railway system.

Of special interest, also, is the fact that a number of the steam railways are seriously considering the electric equipment of short branch lines, which, in several cases, has either been done, or is being undertaken. The much-talked-of project of a high-speed elevated electric railway between Chicago and St. Louis, it is understood, has been definitely abandoned.

It would be interesting to have, at this time, the statistics of the electric railway mileage of the United States, to exhibit the remarkable progress that is being made in this branch of our transportation system, but the data are not as yet accessible.

In relation to the storage battery, though no radical improvement in construction has appeared, the experience gained in connection with its auxiliary employment at central stations, has demonstrated that there may be opened for it in this direction a wide field of usefulness. The prolonged and almost continual litigation over the question of patent rights has, up to the present, greatly interfered with the proper development of the storage battery in this country. Within the past few weeks, however, the official announcement has appeared that one of the prominent companies has acquired a practical ownership of the fundamental storage battery patents. As the transfer of these patent rights to a single ownership will put an end to the deplorable legal complications which heretofore have deterred the public from taking any interest in the application of the storage battery, there is at length a prospect that the free development of the industry will be unhindered, and that

we may soon learn what are the real capabilities of this interesting type of apparatus.

During the past year a successful trial on the Erie Canal of the method of electric traction for canal towage attracted considerable attention, and led many to believe that steps would be taken promptly to test the efficiency of the system on a more extended scale. Thus far, however, nothing of importance has developed in connection therewith on this side of the water, although it may be of interest to notice the fact that a successful trial of the De-Bovet system of electric traction for canal boats recently took place on the St. Denis Canal, in France. A series electric motor actuated the towing pulley, a fourteen millimeter chain, placed at the bottom of the canal, being carried over the pulley to the extent of three-quarters of a turn, although half a turn suffices. A two-wire circuit running along the bank of the canal was connected to a 110-volt generator driven by a locomotive engine. The current was collected by means of two trolleys running along the wires and connected to the motor by a flexible cable, which was passed over a pulley at the top of the mast of the boat. The trial was completely successful, and showed that for an expenditure of 2,000 watts it was possible to make a 300-ton barge move at the rate of 2·8 kilometers per hour. The getting under way took place without shock, and the normal speed was rapidly reached.

The decision of Judge Carpenter, of the United States Circuit Court, in the suit instituted by the Attorney-General of the Uuited States against the Bell Telephone Company, praying for the repeal of the letters-patent No. 463,569, issued November 7, 1891, to Emil Berliner, and assigned to the company above named, has brought to a termination a case of unusual importance, not only in reference to its bearing on the telephone business, but also because of its disclosure of methods and usages in vogue in the United States Patent Office, which call peremptorily for substantial reform.

The decision of the Court was favorable to the contention of the plaintiff, and the Berliner patent was accordingly decreed to be void, and was ordered to be delivered up to be cancelled. The effect of the decision—if it should be sustained on an appeal, which will doubtless be taken—will be to throw open to the public all the essential elements of the art of telephoning. The present status of the art, in view of this decision, is concisely summarized in a recent editorial abstract which appears in the *Electrical World*, from which I quote the following paragraph:

"By reference to the detailed examination of the situation, it will be seen that at present all forms of telephone receivers and transmitters are free, and on January 15th the valuable patent on the use of the induction coil with the transmitter will expire. As a consequence, private lines may be installed and operated under the most advantageous circumstances. The situation as to large exchange stations, however, is still much involved, and, owing to the multiplicity of patents concerned and the scant knowledge on the subject of the requirements of exchanges outside of the Bell companies, it will be some time before it can be cleared up. It now seems that there would be much difficulty in economically operating any exchange of considerable size with-

out the aid of switchboard and other devices covered by Bell patents. When, however, the difficulties to be overcome are clearly defined and understood, the matter will come within the province of the inventor, and the conditions would have to be singular indeed if some method of meeting them could not be eventually devised. But if this should be done, it does not follow that competition with the present local telephone companies would be a simple matter. Their prior occupation of the field, the sagacious preparations, extending over a course of years, that were made with a view to prospective competition, united with a highly trained and efficient force, and exchanges in which the subject of economy of operation has been most exhaustively considered—all of this renders successful competition a question that cannot be taken for granted."

This litigation brought out most conspicuously one fact which, though familiar enough to those who are versed in the patent law and the modes of procedure that obtain in the Patent Office, the layman will learn with amazement. The record of this now famous case exhibits that the application for the patent was filed June 4, 1877, and that the patent was not issued until November 17, 1891, or more than fourteen years after the date of filing. It is thus shown to be possible, by the dexterous use of legal procedures which the usages of the Patent Office permit, for an attorney to delay almost indefinitely final action upon, and the issue of, a patent, whenever the interests of his client will be served by such delay. As I have already intimated, this is no news to the fraternity of patent attorneys, any one of whom will be able to state from the experience of his own practice that the record of this case, far from being in this respect exceptional, could be duplicated. Without venturing upon a consideration of the expediency of investing the Commissioner of Patents with judicial powers capable of such extraordinory exercise, I believe I affirm the opinion of every intelligent and unprejudiced layman in saying that the state of affairs which this case has disclosed constitutes an intolerable abuse which was never contemplated by the framers of the patent laws, and which calls for prompt and radical correction. The decision of Judge Carpenter fortunately paves the way for this much-needed reform, inasmuch as one of the grounds on which he decreed the Berliner patent to be void was the unwarrantable and unlawful delay in the issue of the patent which was intentionally acquiesced in by the Bell Company, and which thus constituted a fraud practiced upon the public.

In the field of electro-chemistry, there has been an unusual amount of activity, and the application of electrolytic methods in the service of the chemical and metallurgical industries has made substantial progress. During the past year an enormous electric refining plant was erected at the works of the Anaconda Copper Mining Company, in Montana, for refining the entire output of those mines. The electrolytic production, by various processes, of caustic soda and bleach from salt; the purification of sewage by electrolytic means; the electric tanning of leather; the electrolytic production of chlorate of potassium from the chloride; of white lead, by decomposing alkaline salts with lead electrodes in the presence of carbonic anhydride; these and numerous other problems in industrial chemistry have been attacked with considerable success.

The brilliant work of Moissan with the electric furnace has shown the feasibility of producing with this agency most of the rarer metals with comparative ease, in considerable quantities, and in a state of purity. The abrasive material called carborundum—one of the latest and most interesting products of the electric furnace—has already acquired an important rank in the industries and is now manufactured in large quantities. The interesting discovery of a cheap method of manufacturing acetylene in quantity by exposing an intimate mixture of lime and carbon to the intense heat of the electric arc in a furnace of this type, has been brought to your notice so recently that extended reference to the very important industrial bearing of the discovery will be unnecessary. * * *

The great problem of converting the potential energy of coal directly into electrical energy, without the wasteful intervention of the steam engine, has received the thoughtful attention of many investigators, and though its satisfactory solution has not yet been found, so much light has been thrown upon the subject that, at the present time, we know much more about the conditions that govern success or failure, than a few years ago. The first serious effort towards the solution of the question was made about ten or twelve years ago by Mr. Edison with his thermo-electric generator, in which he sought to attain the desired end by apparatus of highly ingenious construction, in which the operative feature was the magnetization and demagnetization of iron by rapid alternations of temperature. By the well-known law of induction, these alternations of magnetic intensity were utilized to generate induced currents in surrounding coils. This idea, promising as it appeared when first announced, its originator does not appear to have made any further attempt to develop in practice. What the estimated efficiency of this machine was, I do not at present recall, but it is tolerably safe to infer that it was considerably below that realized from coal through the agency of the steam engine, otherwise something more would have been heard of the invention.

The improvement of the older and better known thermo-electric generators, in which a series of compound bars or plates formed of dissimilar metals, and heated at their points of union, is caused to generate a current, appears also to have been abandoned as a practicable means of solving the problem.

In view of the fact, therefore, that the problem seems to be hopeless of solution from the physical side, it is particularly interesting to note that within the past year the opinion has gained ground that we may reasonably hope to solve it from the chemical side. The correlation between chemical and electrical energy is a well-established fact of science, and, in the case of many substances—carbon among them—is capable of being expressed quantitatively and with as great accuracy as the relation between heat and mechanical force, which finds its mathematical expression in the figures representing the mechanical equivalent of heat. In the voltaic cell, as is well known, the electric energy developed is derived from the direct conversion of the energy of chemical combination, and the quantity of the one, which it is possible to realize from an electrolytic cell formed of any pre-determined elements, may be calculated, in terms of the other, with the same accuracy as the possible

mechanical energy which can be developed from the combustion of a ton of coal. The solution of the problem of converting the potential chemical energy of coal directly into electrical energy, resolves itself, along this line of research, into the construction of voltaic cell in which the "cold" combustion of carbon shall be effected with an efficiency approximating nearly to that which theory demands.

Theoretically, this mode of solving the problem is attended with no difficulties; practically, it presents many, but not insuperable, difficulties. Indeed, although this field of investigation has only recently attracted serious attention, substantial progress has been made towards the actual accomplishment of the object in view. I will refer you, in substantiation of this statement, to the recently published experiments of Dr. W. Borchers, of Duisburg, Germany, who has devised a cell for the purpose in which twenty-seven per cent. of the energy of combustion of the fuel (in this case the combination of CO and O) is converted into available electrical energy. When it is considered that these experiments represent, practically, the first serious attempts at the solution of the problem by this method, these results must impress themselves upon thoughtful persons as very encouraging; especially significant do they appear, when it is remembered that the best results which it has been possible to realize by the indirect method of generating electric currents from coal by the intervention of the steam boiler and engine represent only about fifteen per cent. of the stored-up energy of the fuel.

In a paper before the German Electro-Chemical Society, Dr. Borchers described and illustrated two practical forms of electrolytic cells, one for using carbonic oxide gas, and the other for coal dust, and concluded by affirming his belief that "the problem of the cold combustion of the gaseous products of coal and oil, in a gas battery, and its direct conversion into electrical energy, can certainly be accomplished," a statement which, in view of what he has already demonstrated, appears to be quite reasonable.

In the field of industrial chemistry, I may supplement my comments on the progress made in solving numerous problems in commercial electrolysis, by reference to the interesting discovery of Messrs. Cross, Bevan & Beadle, of certain new reactions of cellulose (wood fibre), yielding derivatives which are found to be susceptible of many uses in the industries, and which give promise of even more extensive and valuable applications than that protean material, celluloid. The material is available in six different forms: the crude solution, dense cellulose in the mass, separate films and sheets, films and sheets on cloth backing, porous cellulose, and various admixtures of cellulose with foreign substances. The number and variety of uses suggested, and, in fact, partly realized for these products, are legion, and instead of enumerating them, I will refer you to the paper of Mr. A. D. Little on the subject, read before the Institute early last year and published in the *Journal*.

* * *

In the aluminum industry no pronounced advance may be reported. The electrolytic methods of production, represented by the Hall process in America, and the closely-related methods of Herault-Kiliani and Minet in Europe, still afford the cheapest means of producing the metal. The out-

look for any material cheapening of the cost of producing this metal is not very promising. The present electrolytic methods are susceptible of very little improvement, and the prospect for cheaper aluminum depends either on the discovery of some radically new mode of generating electric current, or of some very greatly improved method of producing the metal by chemical-metallurgical means. As the utilization of the energy of our great water powers promises to afford power at a cost of less than one-eighth of a cent per electric horse-power per hour, there would seem to be very little hope for reduction of cost in this direction. The probability that a chemical method will be discovered that will be capable of yielding the metal at lower cost than the present electrolytic process, it must be confessed, is extremely small. The possibility that such a discovery will ultimately be made, however, exists, and those who are best qualified to pass an opinion on this interesting subject incline strongly to the view that the cheapening of the cost of producing aluminum will be brought about by chemical methods which will enable us either to make the commercially pure metal directly from its ores by a furnace process, or which will enable the electric manufacturers to produce the pure metal from the crude ores without the expensive preliminary purification which is now a large item in the cost of manufacture.

Substantial advances have been made in connection with the production of alloys of aluminum, which are finding application in the manufacture of engineering, physical and draughting instruments, fine balances, domestic sanitary and plumbing appliances, etc.

The complete solution of the problem of soldering aluminum seems to be opposed by the serious obstacle of the high electro-positive nature of the metal. The method proposed by Mr. Joseph Richards, a member of this Institute, in which a small percentage of phosphorus is introduced into the solder employed, appears to have given more uniformly satisfactory results than any other that has thus far been proposed, though it must be said that it still leaves much to be desired.

The use of aluminum for kitchen utensils is steadily extending, and at present is the basis of a considerable industry. The suitability of the metal for vessels employed in the preparation of food has been made the subject of exhaustive investigation, and the consensus of opinion is now entirely favorable to it. From present indications, it appears highly probable that in the course of a few years the consumption of aluminum for kitchen ware will exceed the requirements of any other industry in which this metal is used.

A few years ago a favorite subject of discussion in the technical journals was the question of the permanency of the supply of natural gas. To-day the question is already practically answered by the actual exhaustion of the supply in parts of Pennsylvania and Ohio, and its rapid diminishment in others; while in Indiana the signs of impending exhaustion have already made themselves apparent in the great reduction of pressure. The fact is now fully demonstrated that the productive gas areas are limited in extent, and that the available supply is a rapidly diminishing quantity.

The recent revival of interest in the subject of aërial flight is a noteworthy circumstance, and within the past few years a really astonishing

amount of progress has been made toward the practical solution of this problem. The names which figure most prominently in this interesting field of research are those of Langley and Maxim. The recent experiments of the last named investigator upon a machine of large size attracted widespread attention. They appear to have fairly demonstrated the following facts: That a machine carrying its own engine, fuel and passengers, can be made powerful enough and light enough to lift itself in the air; that an æroplane will lift a considerably greater load than a balloon of the same weight; and that it may be driven through the air at a very high velocity, and with an expenditure of power very much less than that required to drive a balloon at even a very moderate pace; and that a well-made and properly applied screw propeller obtains sufficient grip upon the air to propel a machine at almost any speed, and that the greater the speed the higher the efficiency of the screw.

Commenting on Mr. Maxim's results, London *Nature* believes that they "have certainly forwarded the problem of aërial navigation."

The remarkable experimental studies of Professor Dewar, of the Royal Institution of London, in connection with liquefied oxygen (which he has succeeded by highly refined and original methods, in producing, comparatively speaking, in large quantities), aside from their great scientific interest, have enabled him to demonstrate certain highly important facts that have direct practical bearing. He has been able to verify, for example, what had been before merely a scientific hypothesis, namely, that as metals decrease in temperature their conductivity for electricity increases, and his experiments give the strongest reasons for believing that when the temperature of absolute zero is reached, the metals reach the point of absolute conductivity. Furthermore, he has experimentally shown that the cohesive power of the metals is greatly increased by diminution of temperature.

The tensile strength of iron, for example, is shown to be increased at the temperature of liquid air from thirty-four tons per square inch (at the ordinary temperature) to sixty-four tons, and a like increase of cohesive quality is exhibited by every other metal. The magnetic property also is shown by his experiments to be increased at these low temperatures; an iron bar magnet, for example, showing an increase of fifty per cent. in magnetic strength.

On the other hand, non-metallic bodies are shown to behave in a manner exactly opposite to that of the metals, decreasing in conductivity as the temperature falls. To comprehend the extraordinary conditions of these experiments it must be remembered that the temperature of liquefied oxygen is 182° below zero of the centigrade scale, corresponding to 295° below zero F. At these temperatures, we have matter, as has been tersely stated, in *articulo mortis*. Chemical forces are in complete abeyance. Phosphorus, even, refuses to combine with oxygen, which has become as inert as nitrogen. A few degrees lower, and the last traces of that molecular motion we call heat would disappear, and matter, destitute of all active properties, would be dead.

An item of scientific interest which has given origin to extended discussion, was the announcement made, at the British Association meeting last

summer, by Lord Rayleigh and Prof. Ramsey, of a probable new constituent of the atmosphere. The alleged new element is described by these observers as being characterized by the same inertness as nitrogen, as somewhat heavier than nitrogen, and is believed by them to be present in the atmosphere to the amount of one per cent. by volume. They believe it to be either a new element, or a heretofore unknown allotropic form of nitrogen. The genuineness of this discovery has been called into question by several noted chemists, and especially by Profs. Dewar and Wanklyn. The scientific world must, accordingly, suspend judgment on the subject for the time.

Franklin Institute.

[*Proceedings of the annual meeting, held Wednesday, January 16, 1895.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 16, 1895.

Mr. H. R. HEYL, in the chair.

Present, forty-one members and four visitors.

Additions to membership since last report, six.

The tellers of the annual election held this day, between the hours of 4 and 8 P.M., made their report. The chairman thereupon announced the result of the election as follows:

For *President*	(to serve one year), . . .	JOSEPH M. WILSON.
" *Vice-President*	. . .	(no choice).
" *Secretary*	(to serve one year), . . .	WM. H. WAHL.
" *Treasurer*	(" " "), . . .	SAMUEL SARTAIN.
" *Auditor*	(" three years), . . .	FRANCIS LECLERE.

For *Managers* (to serve three years),

CHARLES H. CRAMP,	EDWARD LONGSTRETH,
GEORGE V. CRESSON,	SAMUEL P. SADTLER,
ALFRED C. HARRISON,	WM. H. THORNE,
EDWIN J. HOUSTON,	JOHN C. TRAUTWINE, JR.

For the *Committee on Science and the Arts* (to serve three years).

C. O. C. BILLBERG,	J. M. EMANUEL,	C. E. RONALDSON,
L. L. CHENEY,	J. LOGAN FITTS,	L. F. RONDINELLA,
JAMES CHRISTIE,	JOHN L. GILL, JR.,	SAMUEL SARTAIN,
D. E. CROSBY,	LEWIS M. HAUPT,	T. CARPENTER SMITH.
WM. MCDEVITT,	STACY REEVES.	

The chairman announced that a vacancy existed in the office of Vice-President, and one also in the Committee on Science and the Arts. It was voted to defer the election to fill these vacancies until the stated meeting of February.

The following nominations were received for Vice-President, viz. Col Chas. H. Banes, Mr. Henry R. Heyl and Mr. G. Morgan Eldridge.

The Secretary presented the annual reports of the Board of Managers, the several standing committees and sections, which were severally accepted.

A recommendation contained in the report of the Committee on Science and the Arts, that the Institute issue diplomas and certificates in certain cases in connection with its reports, was approved.

A vote of thanks was passed to the professors of the Institute and to the gentlemen who have given their services as lecturers. Also, it was voted that the thanks of the Institute be given to Mr. George V. Cresson, of the Board of Managers, for his generous co-operation with the Committee on Instruction in establishing a branch of the drawing school near Germantown Junction.

The meeting voted to defer action until next month on the proposed amendments to the by-laws affecting the organization and government of sections.

The Secretary presented a report of scientific and industrial progress for the year 1894, an abstract of which is published in the *Journal*. He exhibited also the following novelties: A specimen of calcium carbide, prepared by the electric furnace method, by —— Taber, a member of the Institute, and made the experiment of generating acetylene by dropping fragments of the substance into water: Two pieces of sheet aluminum, greatly corroded, which had formed the heel, or re-enforcing piece, of an extension shoe, and which had been worn for about one year. The maker of this shoe had hoped to find in aluminum a metal that would not be attacked by the secretions of the skin. The condition of the pieces showed that the metal was not suited for the purpose. (In view of this observation, some revision of currently accepted statements respecting the ability of aluminum to withstand corrosive influences of this nature, would appear to be necessary: An improved horse-shoe, devised by Mr. M. Hallahan, of New York. The invention is substantially a pad, made of vulcanized rubber, combined with canvas and backed with sole leather. It is a little more than the full size of the horse's foot across the heel, and forms part of the shoe. In applying the devices, the shoer fits the foot and pad with a three-quarter-inch steel shoe of uniform thickness. The space between the pad and the foot should be filled with tar and oakum.

Adjourned.

WM. H. WAHL, *Secretary*.

BOOK NOTICES.

Electric Light Installations—By Sir David Salomons, Bart., M.A. Vol. II. Apparatus.

Sir David Salomon's book bearing this title has been known now for a number of years, and has run through several editions. His previous editions, although, from the title, having to do with installations in general, and hus purporting to be a book of large scope, have, nevertheless, been

confined entirely to the subject of electric lighting by means of accumulators. Vol. II, which now appears, does not seem to deviate from the line of its predecessor. This particular volume is entitled "Apparatus," and is largely descriptive of the specific types of machinery, accessories, etc., which are used in English practice.

While there are portions of the work which might be read with some degree of benefit, as, for instance, the chapters dealing with gas engines as applied to storage battery plants, we cannot but feel that the larger part of the work is of but slight importance. The study of electricity, both theoretical and applied, now comprehends so large a field, that at the best no one can hope to be more than vaguely familiar with the greater part of what is known. This being the case, it seems a pity that so many books should be published, bearing high-sounding titles, and sure to distract the attention of a large number of earnest workers, from books more helpful. The present work is one of a great many which have appeared during the last year or two, and which contain little else than recapitulation of the matter found in any good trade catalogue. To the live electrical engineer this book presents nothing that is new, and nothing that has not been said before, while the beginner would do better to devote his time in mastering the principles, than in expending his energy in reading catalogue descriptions. E. G. W.

Electric Lighting Plants: their Cost and Operation.—By W. J. Buckley. 8vo. Pp. 279. Illustrated. Chicago: Wm. Johnston Printing Company. 1894. Price, $2.

Despite the deprecatory terms in which the author, in the preface, informs his readers that he is "neither electrician, engineer, nor expert, but a salesman," the book he has prepared seems to us to answer the author's expressed purpose very satisfactorily, to wit: "to give intending purchasers of lighting plants such details as may aid them in forming a fair estimate of the cost of construction and operation of their proposed station."

His critical remarks on the various points worthy to be carefully observed by intending purchasers, are really worth attentive consideration, and should be worth to an intelligent reader in that situation many times the value of the book. The tables of costs, estimates, instructions to employés, etc., have practical value. Altogether, we have seen works more pretentiously introduced which were less worthy of perusal than this one. W.

Lettering of Working Drawings.—By J. C. L. Fish. New York: D. Van Nostrand Co. 1894. Obl. 8vo.

Many books have been written on the subject of letters and lettering, but we know of none more useful than this. The work will form a companion, in every sense of the word, to any draughtsman.

Simple rules are given for the construction of the letters, followed by thirteen plates giving specimens of lettering, which have been made up principally from working drawings.

Many of the letters shown are ornate, others are of the crazy order, but all are legible and easily executed with a pen or pencil.

We find trouble in reading the work at night, and hope the publishers will print future editions on paper which is not so highly calendered. R.

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

T. F. TOWNSEND, WEATHER BUREAU, OBSERVER IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR DECEMBER, 1894.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 31, 1894.

GENERAL REVIEW.

The average temperature for December, 1894, 32°·4, is 0°·4 below the average [32°·8] for the past seven years.

The highest recorded temperatures occurred on the 15th, 16th, 17th, 21st and 22d, and were as follows: Immel Reservoir, 66°; Johnstown, 64°; Pittsburgh, 62°, and Smethport, 62°.

The lowest were on the 29th and 30th: Wellsboro, minus 28°; Shingle House, minus 25°; Emporium, minus 18°, and Towanda, minus 16°.

From January 1, 1894, to December 31, 1894, the accumulated excess in daily mean temperature at Philadelphia was 459°; at Erie, 709°, and at Pittsburgh, 580°.

For the same period the deficiency in precipitation, in inches, at Philadelphia, was 0·22; Erie, 7·55, and Pittsburgh, 9·31.

TEMPERATURE.

	Mean Temperature.	*Mean Precipitation, Inches.*
December, 1887, ...	31°·5	3·53
1888, ...	32°·6	3·14
1889, ...	39°·3	2·77
1890, ...	27°·5	3·97
1891, ...	38°·6	4·09
1892, ...	27°·9	1·69
1893, ...	32°·1	3·06
1894, ...	32°·4	3·95

The means of the daily maximum and minimum temperatures, 40°.0 and 24°.9, respectively, give a monthly mean of 32°.4, which is 0°.3 above the corresponding month of 1893.

The average daily range was 15°.1.

Highest monthly mean, 37°.0 at Philadelphia, Weather Bureau.

Lowest monthly mean, 24°.7 at Selins Grove.

Highest temperature recorded during the month, 66° on the 17th at Immel Reservoir.

Lowest temperature, minus 28° on the 29th at Wellsboro.

Greatest local monthly range, 86° at Wellsboro.

Least local monthly range, 47° at South Bethlehem.

Greatest daily range, 40° at Drifton.

PRECIPITATION.

The average precipitation for the State, for the month, 3.95 inches, is 0.77 inches more than the average [3.18] for the last seven years.

General rains prevailed on the 1st, 2d, 8th, 9th, 10th, 11th, 12th, and snow on the 25th, 26th and 27th.

The storm of the 26th was a mixture of snow and sleet, and caused considerable damage to telegraph and telephone lines.

Light snow occurred at a few stations on the 1st, 2d, 9th, 10th and 11th.

The largest monthly totals of snowfall in inches were: Shingle House, 22.5; Honesdale, 21.5; Somerset, 21.0; Lock Haven, 2.10.

An average of 8.7 inches for the State remained on ground at the end of the month.

The largest monthly totals of rainfall and melted snow in inches were: Confluence, 5.93; Somerset, 5.69; Quakertown, 5.33; Pottstown, 5.32; Uniontown, 5.19, and Immel Reservoir, 5.15.

The least were: Greenville, 2.27; Altoona, 2.30; Saegerstown, 2.39; Erie, 2.53; Chambersburg, 2.65, and Oil City, 2.65.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 10; clear days, 10; fair days, 9; cloudy days, 12.

BAROMETER.

The mean pressure for the month, 30.15, is about .09 above the normal. At the United States Weather Bureau Stations, the highest observed was 30.52 at Pittsburgh on the 18th, and the lowest 29.25 at Philadelphia on the 27th.

MISCELLANEOUS PHENOMENA.

Thunderstorms.—West Chester, 12th; Coatesville, 12th; Phœnixville, 12th.

Hail.—Emporium, 10th; West Chester, 26th; Grampian, 10th; Easton, 26th; Dyberry, 11.

Snow.—Hamburg, 27th; Hollidaysburg, 27th; Towanda, 1st, 10th, 27th; Quakertown, 25th, 27th; Cassandria, 24th, 25th, 27th; Johnstown, 26th, 27th, 28th; Emporium, 10th, 26th, 27th; Mauch Chunk, 25th, 27th; State College, 10th, 25th, 26th, 27th; West Chester, 26th; Coatesville, 26th, 27th; Phœnixville 26th, 27th; Kennett Square, 26th, 27th; Westtown, 26th, 27th; Grampian, 26th, 27th; Lock Haven, 25th, 26th, 27th; Saegerstown, 27th; Carlisle, 10th, 24th, 27th; Uniontown, 26th, 27th; Huntingdon, 10th, 25th, 26th, 27th; Lebanon, 25th, 26th, 27th; Coopersburg, 25th 26th, 27th; Drifton, 10th, 24th, 26th, 27th; Wilkes-Barre, 11th, 24th, 26th, 27th; Smethport, 27th; Greenville, 27th; Pottstown, 26th; South Bethlehem, 25th, 26th, 27th; Easton, 27th; Aqueduct, 24th, 26th, 27th; ***Philadelphia*** [Weather Bureau], 26th; [Centennial Avenue], 26th, 27th; Blooming Grove, 25th, 27th; Shingle House, 2d, 13th, 26th, 27th; Somerset, 26th, 27th; Wellsboro, 11th, 27th; Lewisburg, 9th, 25th, 27th; Dyberry, 1st, 2d, 9th, 11th, 25th, 27th; Honesdale, 1st, 11th, 25th, 27th; Salem Corners, 1st, 11th, 25th, 27th, 28th; South Eaton, 27th; York, 26th, 27th; Selins Grove, 26th, 27th.

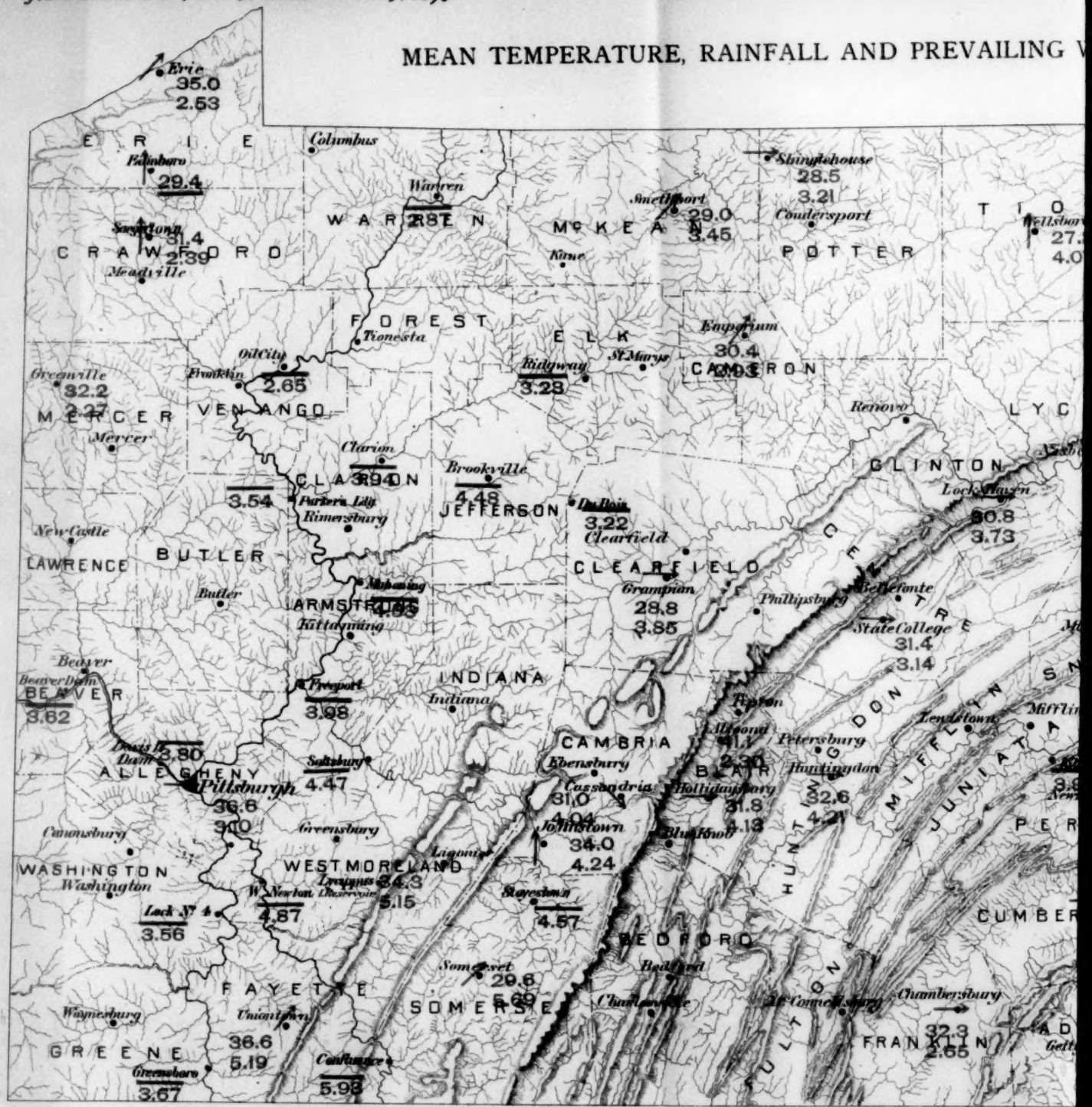
Sleet.—Hollidaysburg, 10th, 24th; Cassandria, 10th, 25th; Johnstown, 10th, 24th; Emporium, 10th; State College, 10th; Coatesville, 27th; Kennett Square, 26th, 27th; Westtown, 27th; Lock Haven, 10th; Lancaster, 26th; Lebanon, 10th; Coopersburg, 1st, 10th, 11th, 27th; Aqueduct, 10th; *Philadelphia* [Weather Bureau], 26th; [Centennial Avenue], 26th, 27th; Somerset, 11th; Dyberry, 2d, 11th; Honesdale, 2d, 11th; York, 10th, 24th, 27th.

Coronæ.—Lebanon, 7th, 12th, 15th; Philadelphia [Centennial Avenue], 14th; York, 7th.

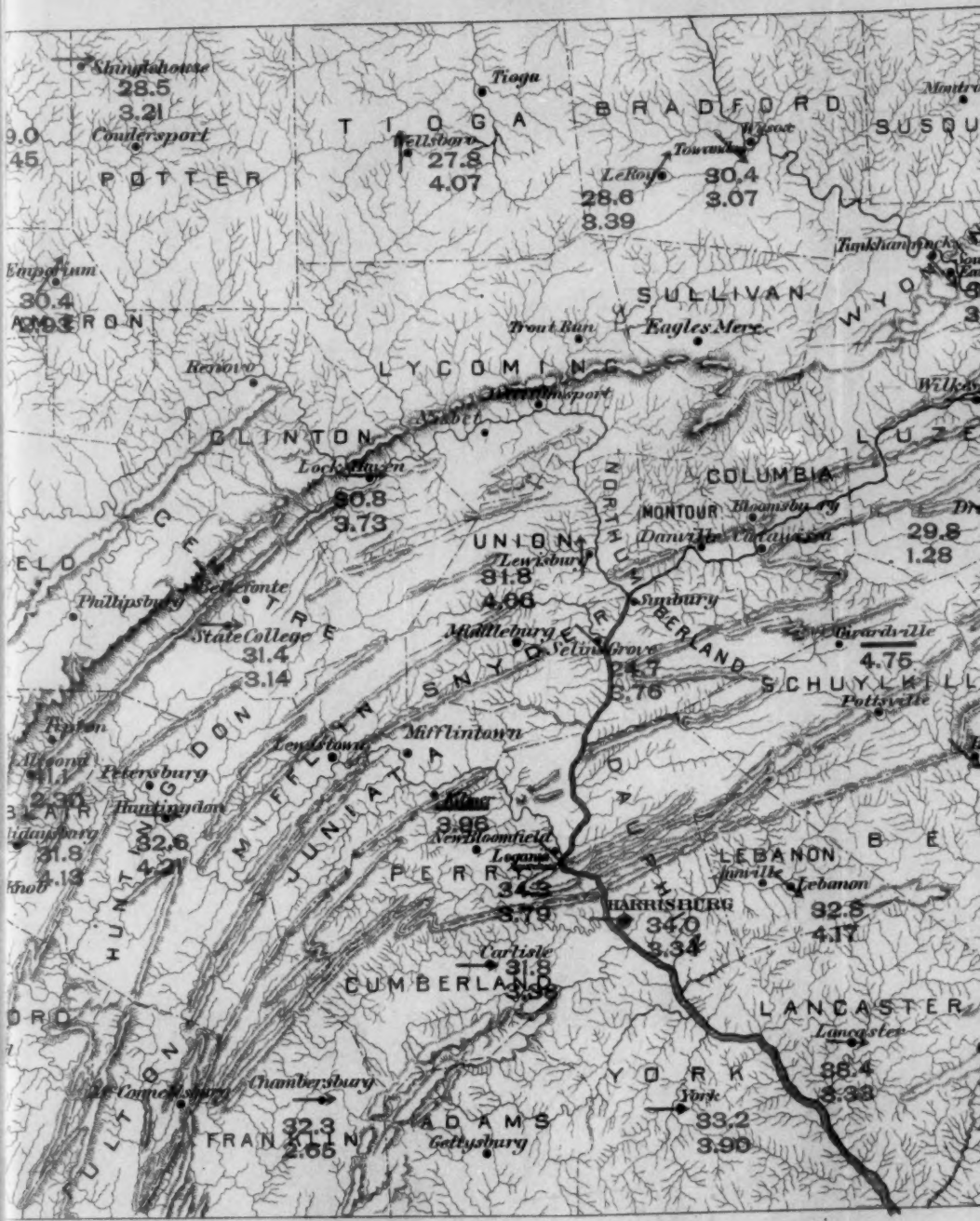
Solar Halo.—***Philadelphia*** [Weather Bureau], 16th, 24th, 26th; [Centennial Avenue], 24th, 26th; Somerset, 24th.

Lunar Halo.—Lebanon, 7th, 21st; ***Philadelphia*** [Weather Bureau], 7th, 19th; [Centennial Avenue], 7th.

Parhelias.—Towanda, 28th, 29th.


MEAN TEMPERATURE, RAINFALL AND PREVAILING W
Erie
35.0
2.53
E R I E
Columbus
Edinboro
29.4
Warren
W A R R E N
Smethport
29.0
3.45
Shinglehouse
28.5
3.21
Coudersport
M c K E A N
POTTER
Sugar Long
31.4
2.39
Meadville
C R A W F O R D
Kane
F O R E S T
Tionesta
E L K
Emporium
30.4
3.93
CAMERON
Oil City
Franklin
2.65
Ridgway
3.28
St Marys
Greenville
32.2
2.27
M E R C E R
VENANGO
Mercer
Clarion
CLARION
3.94
Brookville
4.48
JEFFERSON
Reynoldsville
3.54
Porters Ldg
Rimersburg
DuBois
3.22
Clearfield
CLEARFIELD
CLINTON
Lock Haven
30.8
3.73
New Castle
LAWRENCE
BUTLER
Butler
Mahoning
ARMSTRONG
Kittanning
Grampian
28.8
3.85
Phillipsburg
Bellefonte
State College
31.4
3.14
Beaver
Beaver Dam
BEAVER
3.62
Freeport
3.98
INDIANA
Indiana
Ryton
Altoona
31.4
2.30
Petersburg
Huntingdon
32.6
4.21
Lewistown
CAMBRIA
Ebensburg
Cassandria
31.0
4.04
Johnstown
34.0
4.24
Blair
Hollidaysburg
31.8
4.13
Blue Knob
Davis Is Dam
3.80
ALLEGHENY
Pittsburgh
36.6
3.10
Saltsburg
4.47
Greensburg
Latrobe
Ligonier
Connellsburg
WASHINGTON
Washington
WESTMORELAND
Lock N° 4
3.56
W Newton
4.87
Loyalhanna Reservoir
5.15
Stoystown
4.57
BEDFORD
Somerset
29.6
5.69
Bedford
Chambersburg
32.3
2.65
FRANKLIN
FAYETTE
Uniontown
Waynesburg
SOMERSET
Connellsburg
36.6
5.19
GREENE
Greensboro
3.67
Confluence
5.93
HUNTINGDON
FULTON
MIFFLIN
JUNIATA
CUMBER
PER

RAINFALL AND PREVAILING WIND DIRECTION FOR DECEMBE



Montrose
SUSQUEHANNA
WAYNE 26.8
Dyberry 3.89
Honesdale
29.7
4.05
Scranton
30.4
3.41
29.4
2.61
Bloomsburg
28.3
P 4.15 K E
Milford
Wilkesbarre
32.2
8.66
MONROE
Stroudsburg
Drifton
29.8
1.28
BARBON
Mauch Chunk
31.6
4.05
NORTHAMPTON
Easton
31.6
3.55
4.75
Pottsville
Lynnport
LEHIGH
Allentown
Hamburg
32.9
3.61
Doylestown
3.89
Reading
31.9
4.00
MONTGOMERY
Pottstown
34.3
5.82
Norristown
Bridgeville
Phoenixville
34.5
CHESTER
34.2
West Chester
4.25
37.0
4.03
Media
DELAWARE
Kennett Square
35.0
4.34